2008 Index Streamflows for Massachusetts

April 2008

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Office of Water Resources

For
Massachusetts Water Resources Commission

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1.0 Introduction

1.1 Purpose

This document explains the rationale and development of Index Streamflows for Massachusetts. It presents the Index Streamflows adopted by the Massachusetts Water Resources Commission on (DATE). Index Streamflows are intended to represent the range of natural streamflow conditions that would be expected in the absence of significant human alteration, while recognizing that very few streams in Massachusetts are unimpacted and that a return to natural conditions is neither expected nor practical. Maintaining a natural flow regime is recognized as a key to sustaining native aquatic species. The document provides streamflow statistics from index gages in and around Massachusetts, examples of how Index Streamflows may be applied, and alternative site-specific methods for determining appropriate streamflows that are protective of aquatic habitat. Index Streamflow statistics are developed using three different approaches:

- Target Hydrograph Approach;
- Aquatic Base Flow methodology; and
- Indicators of Hydrologic Alteration (IHA) method.

Each of these approaches is described in further detail in the following sections.

The Department of Conservation and Recreation's Office of Water Resources worked with a Task Force to develop the Index Streamflows utilizing stream flow data measured at selected gaging stations on rivers in Massachusetts and others from adjacent Southern New England states. The Index Streamflows approximate natural flow conditions in magnitude and seasonal patterns in streams not significantly altered by human activities. Therefore, rivers with similar characteristics are expected to be capable of sustaining healthy stream ecosystems. Site-specific studies are preferable for determining the streamflow characteristics needed to maintain a healthy aquatic ecosystem. However, recognizing that time and funding may preclude implementation of site specific studies, Index Streamflow statistics may be used in their place. Also, site-specific studies require intensive time and field efforts, and the results of such studies cannot necessarily be transferred to other locations. Index Streamflows provide the generalization needed for application in a regulatory framework.

The need to characterize streamflows that support healthy aquatic ecosystems is evident in the growing concern over the ability of the State's water resources to meet all demands including environmental protection. Seasonal concerns are most evident during late summer, when streamflows are naturally low, and water supply demands are high. The concern is particularly acute during periods of drought, and may be evident more frequently in watersheds exhibiting signs of stress due to an imbalance between supply (e.g., precipitation and groundwater recharge) and demand (e.g., withdrawals and out-of-basin transfers). Sustainable water management is critical to our ability to meet public water supply needs now and in the future. Moreover, the viability of the state's fisheries, agriculture, recreation and tourism, and other economic activities are also dependent upon the reliable availability of suitable quality water. Therefore, the purpose of developing Index Streamflows is to identify instream flow targets that allow for maximum sustainable use of the Commonwealth's waters and that are protective of the biological, chemical, and physical integrity of those waters.

The Index Streamflows presented in this document may be compared to other river flows in Massachusetts and be considered targets for streamflows that would support healthy aquatic ecosystems. The statistics in this document alone do not imply the Index Streamflows as a regulatory requirement until or unless they are referenced in a regulatory framework. Index Streamflows represent a goal against which streamflow statistics from other rivers in Massachusetts can be measured to indicate their hydrological integrity or degree of flow alteration. They can be used:

- in absence of site-specific studies;
- to represent a range of flows that can be expected in naturally-flowing rivers based on historic records of the least-impacted gaged rivers in Massachusetts and Southern New England;
- in place of, or to supplement, the US Fish & Wildlife Services' New England Aquatic Base Flow standards;
- to serve planning and regulatory needs, although the details of how they would be implemented are not prescribed in this document;
- as a basis for future basin stress reclassification;
- in DEP's New Source Approval site screening process or to condition withdrawals regulated under the Massachusetts Water Management Act; and
- to supplement and update DCR (former DEM) Basin Plan flows.

1.2 Background

At its January 9, 2003 meeting, the Massachusetts Water Resources Commission (WRC) directed its staff to develop a streamflow policy for Massachusetts as part of its annual work plan. The WRC recognized that adequate streamflows are critical to the future of the Commonwealth because of their importance in maintaining habitat for fisheries and wildlife, recreational opportunities, pollution assimilation capacity, and drinking water supplies. The WRC also recognized that several rivers in Massachusetts already had streamflow regimes that were altered to the extent that they no longer served many of these important functions and that the state needed to take action to protect rivers from additional impacts, and possibly to restore adequate streamflow in the future. This request for a streamflow policy followed, and was seen as linked to the development of Stressed Basins classifications in Massachusetts.

Massachusetts rivers were classified in 2001 using an interim Stressed Basins methodology developed for the WRC (Massachusetts Water Resources Commission, 2001). River basins with USGS gages with at least 25 years of flow record were classified as either High, Medium, or Low Stress, or Unassessed (meaning there was insufficient information to place them in any category). Stream flow data from 71 gages were used as the source for the classifications. The stress designations were based upon three low flow statistics to identify rivers with low summer flows (regardless of the cause of the low flows) which would warrant additional environmental review and protection. A more specific streamflow policy or standard was envisioned to improve the Stressed Basins methodology, and additional elements were expected to be incorporated (including biological and chemical indicators of stress), enabling a more refined approach. Also it was felt that the US Fish & Wildlife Service's Aquatic Base Flow default streamflows, although widely used, were often not directly applicable to rivers in Massachusetts because they were derived from a group of stream gages in northern New England with larger drainage areas and more snow pack than typical in Massachusetts river basins. More state-specific analysis was needed.

A work group was established in 2003 to research and develop a streamflow policy for Massachusetts. An update on streamflow policy was provided to the WRC at its meeting in April 2003, where staff presented instream flow protective strategies that were being developed in other New England states. At the September 2003 WRC meeting, the U.S. Geological Survey (USGS) gave a presentation on the statewide research it was undertaking to evaluate streamflow requirements for aquatic habitat protection in Massachusetts (now published in Armstrong, et al., 2004).

Streamflow policy development was supported by USGS Water Resources Investigations Report 03-4332, "Evaluation of Streamflow Requirements for Habitat Protection by Comparison to Streamflow Characteristics at Index Streamflow-Gaging Stations in Southern New England." The report was published by USGS early in 2004, with joint funding from the Department of Conservation and Recreation. As part of this study, streamflow statistics were developed for 23 "index stations" in southern New England, intended to represent the least impacted streamflow conditions in Massachusetts.

A Streamflow Standards Task Force was formed early in 2004, comprised of the streamflow policy work group and a wide range of interested stakeholders. Streamflow Standards were envisioned to represent a goal against which Massachusetts rivers could be measured to indicate their hydrologic integrity or degree of alteration or impact. The terminology was subsequently changed from Streamflow Standards to Index Streamflows to more accurately reflect the nature and intended use of the data. (The term "standard" was often mistaken to impart a direct regulatory flow limit, which was not the intent.)

During 2004, the Massachusetts Executive Office of Environmental Affairs (EOEA) completed a comprehensive Water Policy that addressed many aspects of Massachusetts water resources, including the need to refine the Stressed Basins Methodology that had been utilized since 2001. The Index Streamflows for Massachusetts presented in this report are intended to be incorporated into the Water Policy as a tool for further refinements of the Stressed Basins methodology and an overall Stress Framework, described in the Massachusetts Water Policy (2004, EOEA), as "The Stress Framework would set performance standards for the overall basin based on streamflow and, later, biological and chemical integrity. It would also identify performance standards for specific infrastructure and resource management issues, such as Infiltration-Inflow, Combined Sewer Overflows, and Target Fish populations, and establish a menu of targeted recommendations and requirements, including actions to promote water efficiency and conservation, peak pricing strategies, infrastructure maintenance, planning, and water banking (both within a community and across communities)."

A draft version of Index Streamflows was presented to the Massachusetts Water Resources Commission at its April 2006 meeting, and discussed with the Task Force in May 2006. Based upon the Task Force's feedback, a number of changes were made. This document incorporates the edits based upon the Task Force's suggestions. We have also added explanatory language, some of which has been heavily borrowed from the Rhode Island Department of Environmental Management (RIDEM) 2003 proposed Modified Aquatic Base Flow (RI-ABF) for Rhode Island. The authors thank both the Task Force for its time and input to the process, and Alisa Richardson of RIDEM for permission to use the Rhode Island document.

In October 2007, availability of the Draft Index Streamflows was noticed in the Massachusetts Environmental Policy Act (MEPA) Environmental Monitor and the document (along with computer files containing statistical calculations) was made available on the Water Resources Commission's (WRC) web page for public review. The document was provided in electronic form to Task Force members and to WRC Commissioners at that time. Written comments were solicited in the Environmental Monitor. A presentation of the Index Streamflows was made at the January 2008 WRC meeting and public comments were also accepted at that time. This 2008 draft final version of Index Streamflows incorporates the written and oral comments received on the document through the public review process. In addition, a more complete set of 61 index gages for Massachusetts and southern New England and their flow statistics from USGS (Armstrong et al., 2007) have been incorporated into this document, using the same methodologies that were described in the draft document (which only contained statistics for 23 index gages previously published by USGS (Armstrong, et al., 2004).

1.3 Application

This Index Streamflows document presents three different sets of statistics for benchmarking streamflows in Massachusetts:

- Annual Target Hydrograph (monthly quartile flows derived from daily flows);
- Aquatic Base Flow or ABF Approach (median of monthly mean flows); and
- Indicators of Hydrologic Alteration or IHA statistics (a group of statistics representing magnitude, duration, frequency, and rate of change in streamflow).

All three sets of statistics are derived from data for index gages on rivers in and near Massachusetts that were selected by the U.S. Geological Survey (USGS, Armstrong, et al., 2004 and USGS, Armstrong, et al, 2007) as having minimal flow alterations. The Commonwealth has a history of several centuries of intense land and water use and some areas have been developed beyond the capacity of their water resources. Water resources in Massachusetts are used for a multitude of purposes and many have been altered and impacted by our history. It is acknowledged that streamflows and ecological conditions may never be restored to their natural state. The goal of the Index Streamflows is to represent near natural or least impacted flow conditions. Where possible, water resource management should be undertaken in a way to improve or restore instream ecological conditions, and where significant impacts have not yet occurred, streamflow alterations should be minimized. Where development occurs, efforts should be made to retain natural stream flow characteristics to the extent possible.

Sophisticated rainfall-runoff and regional ground water models have been developed for some areas in the Commonwealth, and have been used to evaluate water management alternatives. Where adequate studies exist, their use is encouraged in tandem with, or to supersede, the relatively simplistic Index Streamflows. The Index Streamflows presented herein are intended for use in locations that have not had the benefit of in-depth scientific studies. Any entity that disputes the applicability of Index Streamflows to a specific location and purpose or seeks more detail is encouraged to undertake a site-specific study to characterize appropriate index streamflow conditions; and/or to establish more applicable flow thresholds for seasonal aquatic habitat needs. Use of composite methods to determine instream flow needs for a specific river may be the most robust means of evaluating the relationships between flow and aquatic habitat. Results from site-specific flow and aquatic habitat studies cannot necessarily be applied to other rivers, however, even within a close geographic proximity (Parker et al., in publication). Additional information regarding site-specific study methodologies and example applications are included in Section 4 of this document.

As scientific advances are made, new data will become available that may help refine Index Streamflows for Massachusetts and flow needs for aquatic habitat. In particular, the USGS continues research into index gage flow characteristics, and aquatic habitat flow requirements, in cooperation with state agencies. Therefore, the Index Streamflows identified in this document should be considered interim until new research data and results are available that can be incorporated into the analysis.

These Index Streamflows should be implemented as an interim measure to begin protecting and restoring Massachusetts' aquatic habitat. As eloquently stated in *Rivers for Life: Managing Water for People and Nature*, by Sandra Postel and Brian Richter, (Island Press, 2003):

> Each river-dependent animal or plant has different habitat needs or preferences, which typically vary during their life cycles, as well as different tolerances for unfavorable conditions. A river's native species have been "tested" by nature's variability over thousands of years. If individuals are able to grow and reproduce adequately when conditions are favorable, and their population does not lose too many members during hard times, the species is able to persist. When humans alter the natural variability in river flow, they change the probabilities of survival for each species.
>
> The flow of water in a river is not the only factor influencing the plants and animals in river ecosystems. The chemistry and temperature of river waters greatly influence river life. Sunlight penetrating the water drives the growth of aquatic plants. Leaves and other detritus falling or washing into a river supply food to insects at the base of river food chains. The amount and size of sediments—sand, gravel, and cobbles—moving through a river affect the physical structure of river channels and floodplains. The fate of many river species depends on the species they feed upon, get eaten by, or compete with. However, each of these other factors, in turn, is affected by river flow to varying degrees, making the flow regime a powerful influence on river health.
>
> And:
>
> Together, adaptive management and the natural flow paradigm are powerful tools for improving river governance. The natural flow paradigm says, in effect: it is not necessary to know exactly how sediment-dwellers keep the ecosystem's food web humming, or exactly what conditions riparian

communities need for regeneration, or exactly how much water and at what time each river species needs to survive. Historically, the river's natural variation in flow took care of these critical elements. For its part, adaptive management says: there is no rational reason to stay in gridlock; actions to restore flows can get under way even in the face of some uncertainty.

2.0 Index Streamflows for Massachusetts

The Task Force conducted a thorough review of desktop standard-setting instream flow methods, as well as site-specific study methods. Some of the desktop methods reviewed include the US Fish and Wildlife Service Aquatic Base Flow Method (USFWS ABF, USFWS, 1981; Lang, 1999) and the Tennant Method (Tennant, 1976). Field methods reviewed included the Wetted Perimeter Method (Leathe and Nelson, 1986) and R2Cross (Espegren, 1996). The site-specific Instream Flow Incremental Method (IFIM, Bovee et al., 1998) was also reviewed. Detail regarding some of these site specific methodologies is provided in Section 4.4. Flow standards developed by desktop methods lack the ability to quantitatively and incrementally assess the relationship between habitat availability and flow. Given this uncertainty, flow standards derived from desktop methods are usually conservative in terms of the resource protection.

The following Index Streamflow statistics were selected to represent the characteristics of natural streamflow in Massachusetts. This report does not recommend one set of statistics over the others; the application and the degree of data availability may dictate which methods are most appropriate for use. Site-specific study will almost always provide the best assessment of streamflows appropriate for aquatic habitat; however, even with site-specific studies there are varying degrees of analysis and different goals for establishing target streamflows (i.e., seasonal values, monthly values, low-flow frequencies and duration, peak flow targets).

2.1 Basis

The structure and function of riverine systems are based on hydrology, biology, geomorphology, water quality, and connectivity. The proposed Index Streamflows are intended to characterize a natural flow regime that will in turn protect aquatic life functions dependent on the natural flow regime. Research has found that aquatic biota are dependent upon basic hydrologic cycles and the natural flow regime. Significant disruptions in any of these features of the flow regime can be detrimental to natural biota. For example, changing the timing of releases in the spring affects natural spawning cues of anadromous fish. Loss of flooding flows results in changes to riparian zones, and subsequent siltation of gravel beds can degrade or remove spawning habitat. Information regarding how flows affect the natural biota can be found in the book "Instream Flows for Riverine Resource Stewardship" by the Instream Flow Council, 2004.

2.2 USGS Index Gage Study

Massachusetts Index Streamflows were selected to represent the natural range and variation of flow at the least hydrologically altered sites in Massachusetts. The streamflows were in part based on research conducted by the USGS through its cooperative program with the Massachusetts Department of Conservation and Recreation, and the Department of Fish and Game, Division of Fisheries and Wildlife, and published in the reports (hereinafter referred to as the “Index Gage Reports”):

Armstrong, D.S., Parker, G.W., and Richards, T.A., 2004, Evaluation of Streamflow Requirements for Habitat Protection by Comparison to Streamflow Characteristics at Index Streamflow-Gaging Stations in Southern New England: U.S. Geological Survey Water-Resources Investigations Report 03-4332

and

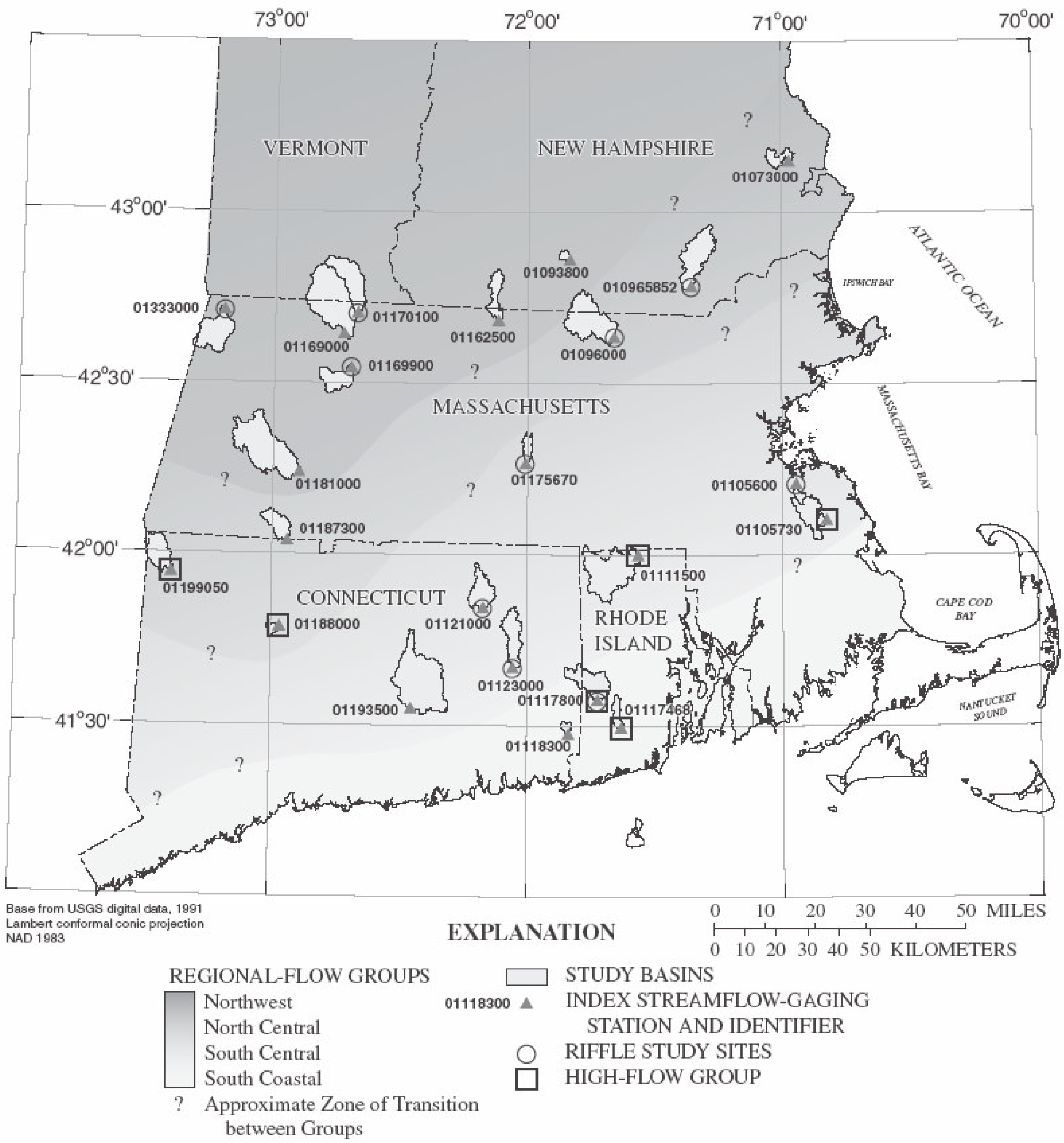
Armstrong, D.S, Parker, G.W., and Richards, T.A., 2007, Characteristics and Classification of Least Altered Streamflows in Southern New England: U.S., Geological Survey Scientific Investigations Report 2007-5291.

The complete 2004 Index Gage Report is available for download from the USGS web site: http://water.usgs.gov/pubs/wri/wri034332/ An important errata sheet was published for the report to correct some tables and is available at: http://water.usgs.gov/pubs/wri/wri034332/control/Erratum_WRIR03-4332.htm. The 2007 Index Gage Report is in publication and should be available on-line during 2008.

The 2004 Index Gage Report identified 23 active streamflow gaging stations in southern New England with a long period of coincident record, and which were believed to be the least impacted by water withdrawals or regulation. The stations had a 25-year common period of record, from 1976 through 2000. Annual hydrographs were developed for each index gage, using median monthly streamflows (the 50th percentile monthly flow duration) normalized by drainage area. These hydrographs were used to classify the index stations into groups with similar median monthly flow durations. For the high-flow season (November through May), the index gages were divided into four regional groups, forming bands that generally parallel the southern New England coast. For the low-flow season (June through October) the index gages were divided into two groups on the basis of the percentage of sand and gravel in the contributing area and a base flow index. Locations of the index stations and the four regions of Massachusetts are shown in Figure 5 of the 2004 Index Gage Report , reproduced here as Figure 2.1.

The 2004 Index Gage Report also evaluated streamflow requirements for aquatic habitat protection at the index gages using various well-known methods: the Range of Variability Approach (RVA), the Tennant method, and the New England Aquatic Base Flow Method (ABF). In addition, field investigations were performed near 10 of the index gage stations, by applying the Wetted-Perimeter and R2Cross methods to identify streamflows protective of aquatic habitat. Table 17 of the 2004 Index Gage report presented a summary of summer streamflow requirements and corresponding annual flow durations for the index gage stations in southern New England. Table 17 summarized streamflow needs for both the low- and high-flow designated rivers. The results, summarized in Appendix A, ranged from 0.19 cfsm to 1.3 cfsm, and corresponded to annual flow durations of 97th to 54th percent exceedance. While these results are not directly used to characterize Index Streamflows in Massachusetts, they represent a good baseline for beginning to evaluate instream flows for habitat needs and characterize some of the methodologies used in these determinations.

Figure 2.1 Massachusetts Index Gage Stations (Armstrong, et al., 2004)



Fish population surveys conducted by the Massachusetts Division of Fisheries and Wildlife (DFW) were combined with habitat-use classifications to produce an assessment of fish-community composition for river reaches near the index gage sites in Massachusetts for the 2004 report. Although some of the fish communities at index gage stations are heavily impacted, most maintained a high proportion of fluvial (riverine) fish species indicating that the hydrologic integrity was at least somewhat intact at those sites. USGS and DFW research is currently underway that will provide more quantitative site-specific fish community assessment.

Use of the flows observed at index gages as baseline conditions for Massachusetts links biological integrity to streamflow. Fish community structure and ecological integrity of freshwaters rely on many factors. Hydrologic integrity does not by itself determine ecological integrity. Water quality, connectivity, biology, and geomorphology together with hydrology determine ecological integrity. Fish data, as a surrogate for the biological component, can be a critical aspect of any resource management decision. Biological information, in conjunction with flow data can lend insight into watershed and site-specific impacts. The biological information at the majority of the Index Gage sites indicates that most of these rivers have not yet lost the ability to sustain fish communities dominated by fluvial fish species.

Geographical gaps of index gages were identified in the USGS 2004 Index Gage Report. As a result, USGS and DCR continued the research on index gages to identify additional gages that would meet criteria as index gages and to document index gage flow characteristics. The USGS 2007 Index Gage report contains flow statistics for an expanded set of 61 index gages for Massachusetts, including both active and discontinued gages. The updated 2007 Index Gage report also analyzes statistical properties of streamflow at the index gages and develops hydrologic classifications of rivers in southern New England with similar hydrologic properties. The study concluded that geographical location alone is not adequate to group rivers with similar streamflow characteristics.

It is acknowledged that the index gages are not entirely without flow impacts; rather, they represent the gaging stations with the least impacted streamflows that could be identified on Massachusetts rivers and in adjacent states. The index gages are subject to varying degrees of development and other flow-altering structures and activities (e.g., small upstream withdrawals, discharges, or dams may be present). In its 2007 Index Gage report, the USGS evaluates water withdrawals, water returns, number of dams, and land use at each of the index gages. Basin characteristics of the 61 index gages (Armstrong, et al., 2007) are summarized in Table 2.1. These are the set used for Massachusetts Index Streamflows.

2.3 Annual Target Hydrograph Approach

At its August 25, 2004 meeting, the Streamflow Standards Task Force adopted a proposal that target flow hydrographs be developed for Massachusetts. Regional annual hydrographs would be developed for Massachusetts, based on the four regions identified in the Index Gage report and monthly values from the USGS index gages. The hydrographs would consist of median monthly flows surrounded by a range defined by the 25th and 75th percentile flows. It was proposed that the hydrographs would represent flow goals for Massachusetts rivers and could be considered restoration targets at locations where these flows are not currently met. The hydrographs would describe a natural range of flows throughout the annual hydrological cycle and could be used as presumptive standards in lieu of site-specific studies. Data from non-index gaged rivers could be compared to the target hydrographs to assess the degree of flow impact experienced at the non-index gaged rivers.

The target hydrographs are based upon median monthly flows surrounded by the interquartile range (25th to 75th percentiles). The selected statistics are reasonably simple to calculate for a gaged river and do not require additional field work. The interquartile range approach is consistent with the one proposed by The Nature Conservancy in its "Range of Variability Approach" (RVA, described in: How Much Water Does a River Need?, Richter et al., Freshwater Biology, (1997) 37, 231-249). The RVA methodology suggests a range of flows within the monthly 25th to 75th percentiles of a suite of flow statistics (e.g., monthly streamflows in this example) as initial streamflow management targets. Using monthly statistics, the management goal would be to keep streamflow near the normal range of flow of the appropriate index gage. The range of variability for rivers should remain similar to the range described by the index gages. It is acknowledged that the quartiles of monthly streamflows are not met on average 50 percent of the time in a natural condition. The expectation is that actual streamflows for the index rivers will be below the Index Streamflows 25 percent of the time, and will be above the Index Streamflows 25 percent of the time on average. Deviations from the Index Streamflows are expected due to differences in weather conditions from year to year. However, at the time an appropriate index gage is within the "normal" range of the 25th to 75th percentile flows, it is expected that an un-impacted river would exhibit a similar magnitude of flow, on a per-drainage-basin-area basis.

The Nature Conservancy also advocates for maintenance of other ecological flow components (EFC) in addition to the monthly quartiles of flow (Mathers and Richter, 2007). These include elements such as bankfull flows, small floods, and low flows. This wider range of flow characteristics is beneficial to geomorphology of the river and the biology of the aquatic organisms that inhabit the river. These flow components are addressed below in the section describing Indicators of Hydrologic Alteration.

The initial draft of the index streamflow document presented monthly quartile flows in accordance with the 2004 proposal; however, Task Force feedback in 2006 expressed concern that the number of index gages in each region was not statistically sufficient to justify using a regional approach. Also, geographical proximity did not necessarily imply a similarity in hydrologic flow conditions. Geologic conditions within a drainage basin play a significant role in river flow patterns. As a result, the Index Streamflows now include the monthly quartile values (consistent with the RVA Approach), but data are provided for each individual index gage. The user can select the most similar index gage to the stream in question for evaluating appropriate flows, on a cubic feet per second, per square mile area (cfsm) basis. Guidance regarding selection of the most similar index gage is provided in Section 3.4 of this document.

The target hydrographs for each of the index gages were calculated and are presented in Appendix B. For each index gage, the streamflow data from USGS were used to calculate of the 25th, 50th (median), and 75th percentile flow durations for each month of the year for a period between 1960 and 2004 on the basis of calendar year. These statistics are also represented in shorthand as Q25, Q50, and Q75. Because some data from the 61 index gages were estimated by USGS (Armstrong, et al., 2007), the daily streamflow data generated by USGS were used in the analysis for the Index Streamflows. The monthly quartile values were calculated from daily mean flows by DCR. A comment from the Task Force indicated that the statistics would be more rigorous if daily values were used in the computations, rather than monthly values that are more typically used. Based on this, quartile values were calculated using all daily values for a given month covering the 1960 to 2004 period (e.g., the distribution of January flows would consist of 31 days X 45 years, or 1,395 daily values). The calculations were performed using Excel spreadsheets, because the Indicators of Hydrologic Alteration software does not use daily values, rather it uses monthly values to calculate the quartile statistics (personal communication, Tom Fitzhugh, The Nature Conservancy).

The daily streamflow values were divided by the drainage area to each index gage, resulting in units of cubic feet per second per square mile of drainage area (cfsm). Drainage areas and other basin characteristics for the index gages are listed in Table 2.1.

2.4 Aquatic Base Flow (ABF) Method

Index Streamflows for Massachusetts include analysis of index gage data using the US Fish & Wildlife Service's Aquatic Base Flow (ABF) methodology, which establishes seasonal flow standards based upon the median of monthly mean flows (documented in "Questions and Answers on the New England Flow Policy", Vernon Lang, US Fish and Wildlife Service, Concord, New Hampshire, May 11, 1999). Application of the ABF method to index gages provides streamflow information specific to southern New England, and more specifically for Massachusetts, that was not provided in the original USFWS document.

An important ecological underpinning of the USFWS ABF method is that the natural hydrological system serves as a baseline or reference condition that provides stream flow conditions suitable for the protection and propagation of aquatic life. Aquatic life in natural stream systems is subject to an inherently complex array of imperfectly understood relationships and conditions that serve to limit or promote life in lotic environments. The USFWS concluded that aquatic life in free flowing New England streams has evolved and adapted to naturally occurring chemical, physical and biological conditions, and that if these environmental conditions could be emulated, aquatic life would be sustained at a level commensurate with populations existing under similar natural environments. The USFWS ABF has long-standing use in Federal Energy Regulatory Commission re-licensing applications, has been successfully defended in court and is widely used in New England.

In its development of the New England Flow Policy, or ABF, the USFWS used historical flow records for New England gaging stations to describe stream flow conditions that sustain and perpetuate indigenous aquatic fauna. The USFWS evaluated gage data from 48 unregulated rivers with drainage areas greater than 50 square miles (mi^2) and with a 25 year gage record (mainly in northern New England since most in southern New England are heavily impacted by human activities). The USFWS ABF method assumes that the most critical flows to be maintained are in August when the metabolic stress to aquatic organisms is at its highest due to higher water temperatures, diminished living space, low dissolved oxygen, and low or diminished food supply. It was determined that the historical (unaltered) median flows would protect critical reproductive functions. Where adequate records (25 years of unaltered, free-flowing, 50 mi.^{2} or greater USGS gaging measurements) exist, the USFWS recommends that using the median of the August mean flows will provide adequate flow for aquatic habitat needs throughout the year, unless additional flow releases are necessary for fish spawning and incubation. If spawning and incubation are an issue, the USFWS recommends flow releases equivalent to the historical median of monthly mean stream flow throughout the applicable spawning and incubation period. Where inadequate records exist or for rivers regulated by dams or upstream diversions, the USFWS recommends using a default value of 0.5 cfsm unless spawning and incubation are a concern, where the recommendation is 1.0 cfsm in the fall/winter and 4.0 cfsm in the spring.

Refinements were made to the USFWS ABF to develop more representative index hydrographs for Massachusetts. Only seven gaging stations of the 48 selected for the USFWS ABF study were located in Massachusetts. The USFWS normalized flow values (in cfsm) were averaged across all drainages to arrive at an August median flow of 0.48 (which was then rounded up to 0.5 cfsm.) There are hydrogeologic and climatic dissimilarities between areas that were used to develop the USFWS ABF policy and Massachusetts. Many of the rivers used by USFWS were in northern New England areas that have significant snowpack and resulting high spring snowmelt flows. These areas experience higher spring flows at generally later times of the year and lower winter flows than many rivers in Massachusetts. The index gages used in development of Massachusetts' Index Streamflows were located within and closer to Massachusetts than those used for the USFWS ABF, and represent smaller drainages, four to 295 square miles in area; therefore, the target streamflows described herein are likely more representative of small to medium drainage basins in Massachusetts than those used to develop the US Fish & Wildlife Service's Aquatic Base Flow default seasonal streamflows.

The USFWS ABF policy allows for a site-specific analysis to be conducted using available flow data. Where a minimum of 25 years of US Geological Survey (USGS) gaging records exist at or near a project site on a river that is basically free-flowing, USFWS recommends that the ABF flow be equivalent to the average of the median of the mean August flow unless superseded by fish spawning and incubation recommendations. USFWS recommends flow releases equivalent to the historical median stream flow throughout spawning and incubation periods. A proxy to this recommendation would be maintenance of natural median monthly mean flows throughout the year.

ABF method streamflows (medians of the monthly mean streamflows) for each of the index gages are presented in Table 2.3. For each index gage, the USGS streamflow data was analyzed by Massachusetts DCR to calculate the median of monthly mean flows for each month of the year for a period between 1960 and 2004. The flow values were divided by drainage area to the index gages, resulting in units of cubic feet per second per square mile of drainage area (cfsm). Drainage areas and other basin characteristics for the index gages are listed in Table 2.1. The monthly mean flows for each month between 1960 and 2004 were calculated, and then the median of all of the values were calculated for each of the 12 months of the year, for each of the index gages. These tables were used by WRC staff to develop median monthly "ABF" hydrographs. August medians of monthly flows for the 61 index gages used for Massachusetts Index Streamflows range from 0.15 to 0.81 cfsm. The average value for these gages is 0.37 cfsm.

The Massachusetts Index Streamflow policy also recommends site-specific implementation of the ABF policy where data are available. An example is provided in Section 4.2.

2.5 Indicators of Hydrologic Alteration (IHA) Method

The Task Force recognized that the target streamflows for Massachusetts should include additional aspects of the natural flow regime such as magnitude, frequency, durations, timing, and rate of change of flows. The Nature Conservancy has developed a statistical program, the Indicators of Hydrologic Alteration (IHA), which inputs daily streamflow data and computes 33 streamflow statistics plus 34 Environmental Flow component parameters. Details regarding the IHA program can be found at http://www.nature.org/initiatives/freshwater/conservationtools/index.html. The software is available for free download from this web site. The IHA program was utilized to develop streamflow statistics for each of the index gages, for the period of 1960 to 2004. These statistics can be compared to other non-index gages for the same time period, or for alternative time periods. The user should be careful to compare similar time periods for each of the two rivers, because climatic variations can strongly influence the statistical results.

Streamflows for all Massachusetts rivers should mimic the natural flow regime as closely as possible in order to adequately sustain natural hydrology, biology, geomorphology, water quality and connectivity characteristics. The natural flow regime of virtually all rivers is inherently variable, and this variability is critical to ecosystem function and native biodiversity. For this reason, providing a single flow or seasonal value (minimum, optimal, or otherwise) cannot meet the life cycle requirements for all riverine species. The proposed Index Streamflows include a group of flow statistics that represent a range of high and low flow statistics that describe the natural flow regime.

For each index gage, the USGS daily streamflow data were analyzed by WRC staff using the Indicators of Hydrologic Alteration (IHA) software by The Nature Conservancy, version 7.0. The analysis was performed using both the parametric and non-parametric formats, and used all default values within the program, with the exception that rather than calculating the 33rd and 66th percentiles, the program calculated the 25th and 75th percentiles in addition to the median flow for each month for the non-parametric analysis. Output data tables were used by WRC staff to develop IHA flow “scorecards” for each index gage, provided in Appendix C.

3.0 Application of the Index Streamflows

The following section provides guidance regarding application of the Index Streamflows.

3.1 Selection of Most Similar Index Gage

When using the Index Streamflows for comparison to another (non-index) gage or ungaged site in Massachusetts, it is recommended that the user select the index gage with the most similar basin characteristics to the area of concern. Basin characteristics for each of the 61 index gages are provided in Table 2.1. The following drainage area characteristics should be determined for the subject location (the location being compared to the index gage):

- Drainage area, square miles;
- Mean basin slope (percent);
- Basin area of stratified drift per total stream length (square mile per mile); and
- Region (east or west), as defined by Ries and Friesz, 2000.

These basin characteristics were selected from equations for estimating low-flow statistics in Massachusetts developed by the U.S. Geological Survey that ultimately became the basis of the on-line “Stream Stats” application (Ries and Friesz, 2000). These parameters were the most significant determinants for estimating streamflow at a given location in Massachusetts. Drainage area is the most significant factor determining streamflow. However, Index Streamflows statistics have all been normalized by drainage area. The on-line Streamstats application for Massachusetts at http://water.usgs.gov/osw/streamstats/massachusetts.html can provide these basin characteristics for most locations in Massachusetts using point-and-click mapping technology. Drainage area characteristics in Table 2.1 were presented in Armstrong, et al. (2007), based upon GIS analyses. Note that Ries and Friesz (2000) delineated two hydrologic regions of Massachusetts (depicted in Figure 1 of that report), based on the eastern boundaries of the Chicopee and Millers Rivers watersheds, dividing the western region from the eastern region of Massachusetts. DCR used this delineation to estimate the appropriate regions for index gages located outside of Massachusetts for inclusion in Table 2.1.

The most similar index gage should be selected based upon the four basin criteria listed above, in the order listed. An additional factor that should be considered if choosing among a few gages with similar basin characteristics is geographical proximity, to include a similar weather pattern. In general, if a long enough period of record is being analyzed, the weather pattern will even out with time; however, if a shorter time period of data is being compared, the smaller-scale weather pattern becomes more significant.

Consideration should be given to drainage basin size and other pertinent characteristics when applying the Index Streamflows for Massachusetts. Although no study has yet been performed to establish the lower or upper limits of applicability of drainage area, it is probably advisable to compare index gages to other gages with drainage area in the same order of magnitude where possible. Application of Index Streamflows is not appropriate for headwater areas that do not support perennial streams. The USGS Water Resources Investigations Report 02-4043 (Bent and

Archfield, “A Logistic Regression Equation for Estimating the Probability of a Stream Flowing Perennially in Massachusetts”) can be used to establish the likely lower limit of applicability of the Index Streamflows. An upper limit of applicability may occur for very large rivers in Massachusetts with drainage areas above the upper limit of the index gages (e.g., the Merrimack and Connecticut Rivers). Streamflow characteristics in basins with major dams and/or reservoirs are not expected to correlate well with Index Streamflows as a result of the effects of the impoundment storage.

An example of similar index gage selection follows. The user wishes to evaluate flow statistics for a river location with known basin area characteristics. An appropriate index gage must be chosen for comparison, on a per-drainage basin area basis. (Note, this analysis could also be performed to select the most similar index gage to compare to a non-index gage flow record). Characteristics for the location that is to be matched and the index gage selected as most similar are listed in Table 3.1. The hypothetical non-index location has a drainage area of 12.2 square miles, a mean basin slope of 6.00 percent and an area of stratified drift per stream length of 0.0345. It is located in the western region of Massachusetts. Referencing Table 2.1, the index gages with the most similar sized drainage area are: Oyster River near Durham, NH (01073000) at 12.21 square miles, Moss Brook Wendell Depot, MA (01165500) at 12.13 square miles, and West Branch Swift River Shutesbury, MA (01174565) at 12.5 square miles. The best-matching index gage will be selected from among these three. Since all of the index gage flow characteristics are normalized to basin size (i.e., presented in cfsm flow units), basin size need not be the only determinant of the most similar index gage. The second factor to consider is the mean basin slope. Among the three candidate index gages, the Oyster River gage is the closest match for mean basin slope at 4.37 percent. The stratified drift per stream length factor also most closely matches the Oyster River gage. Thus, the best index gage choice for this example appears to be the Oyster River, since it is most similar in all three of the primary basin characteristics. Comparison to the Moss Brook and West Branch Swift index flows may also be considered in this case. The proximity of the hypothetical location with respect to the index gages should also be considered with respect to similarity of climate conditions. The subject river’s location in western Massachusetts suggests that the Moss Brook and West Branch Swift rivers are probably more proximal than Durham, New Hampshire.

Table 3.1 Example of Index Gage Selection

Location	**Drainage Area (mi^2)**	**Mean Basin Slope, %**	**Stratified Drift per Stream Length**	**Region**
Hypothetical Location	12.20	6.00	0.0345	1
Oyster River Durham, NH	**12.21**	**4.37**	**0.0130**	0
Moss Brook Wendell Depot, MA	12.13	10.49	0.1182	1
W Branch Swift R., Shutesbury, MA	12.5	11.17	0.0819	**1**

Note: Best matches for each factor among the index gages considered are shown in bold type

Selections of the most similar index gage to active gages in Massachusetts is presented in Appendix D.

3.2 Significance of Flow Alteration

The Nature Conservancy has developed a framework known as the Limits of Hydrologic Alteration (LOHA) approach (Richter, Apse, and Warner, unpublished manuscript, 2006). This approach, which is currently being prepared for publication in conjunction with a group of international aquatic scientists, links the concept of the biological condition gradient (Davies and Jackson, 2006) with research on the impacts of flow alteration on aquatic ecosystems. In application, the approach provides a framework in which managers define hydrologic criteria by developing quantitative and qualitative relationships between metrics of hydrologic alteration and changes in aquatic ecological integrity. The approach is based upon the natural variation of flow paradigm and the established relationships that link levels of aquatic integrity to the degree of human disturbance (Arthington et al, 2006). Using this approach, once hydrologic criteria have been set, protection strategies can be developed for rivers to ensure they meet the targeted or desired ecological condition, and restoration strategies can be developed for rivers that do not meet hydrologic (and associated biological) criteria. The hydrologic status of rivers can be described in a range from natural or undeveloped, where hydrologic characteristics are altered only slightly, or not at all (such as index gages and index streamflows), to strongly altered, where many hydrologic characteristics are heavily altered. In accordance with this approach, degrees of hydrologic alteration that correspond with different degrees of biological condition can be determined. Research continues to further establish thresholds of hydrologic alteration in Massachusetts. The U.S. Geological Survey is currently conducting such research in Massachusetts (summarized in Section 5.2).

Until further research is complete that can demonstrate appropriate thresholds for biological impact, and thus hydrologic alteration, as a goal, flow statistics from any gaged location in Massachusetts should not vary substantially, on a unit drainage area basis, from the most similar index gage. (It is recognized, however, that streamflows may in some cases actually vary substantially from index flows as a result of alterations.) There are numerous methods for determining "significance" of hydrologic alteration statistically. This document will not specify a limit of statistical significance nor a threshold, but will rather leave that determination to the users of the data, on a case-by-case basis. Use of the term "flow statistics" is intentional in the statement above. It would be inappropriate to simply compare daily flow at one location to another to draw any strong conclusions. Data from an adequately long period of record should be compared for the same time periods (to eliminate any climatalogical influences among the statistics). Ongoing research may soon result in meaningful results that can identify appropriate thresholds of hydrologic alteration that could be applied in Massachusetts. These limits could then be used for future basin stress reclassification and to guide river protection and restoration.

Another, more simple approach would be to assign a limit of alteration for flow statistics (on a drainage basin area) between a non-index gage and the most similar index gage. As an obvious example, a very high degree of alteration such as 500 percent difference of a statistic could safely indicate a high degree of alteration. Using very small percentages of difference between two gages (such as 10 percent) could be subject to error, however, since differences in geology, land use, and other factors may influence flow data beyond the limits of the statistical analysis.

3.3 Limitations of Index Streamflows

The user should consider the context of comparison of Index Streamflows with flows at another river location. Three different sets of flow statistics are provided within this document, and not all may be appropriate for use in all cases. In general, flow statistics including those listed as index flows cannot be directly compared to daily flows being measured at a non-index gage; however, the magnitude of flows for an index gage and a non-index gage can be compared for a similar time period. Where applicable, the USGS StreamStats application can continue to be used to estimate low-flow durations for research or regulatory purposes.

4.0 Example Applications of Index Streamflows and Site Specific Studies

Some examples follow of how the different index streamflow statistics could be used. The section is not meant to restrain other uses of the Index Streamflows; rather, it serves to illustrate different ways that the streamflow statistics can be used to evaluate gaged rivers or to establish streamflow goals for rivers without historic flow information.

4.1 Annual Target Hydrograph:

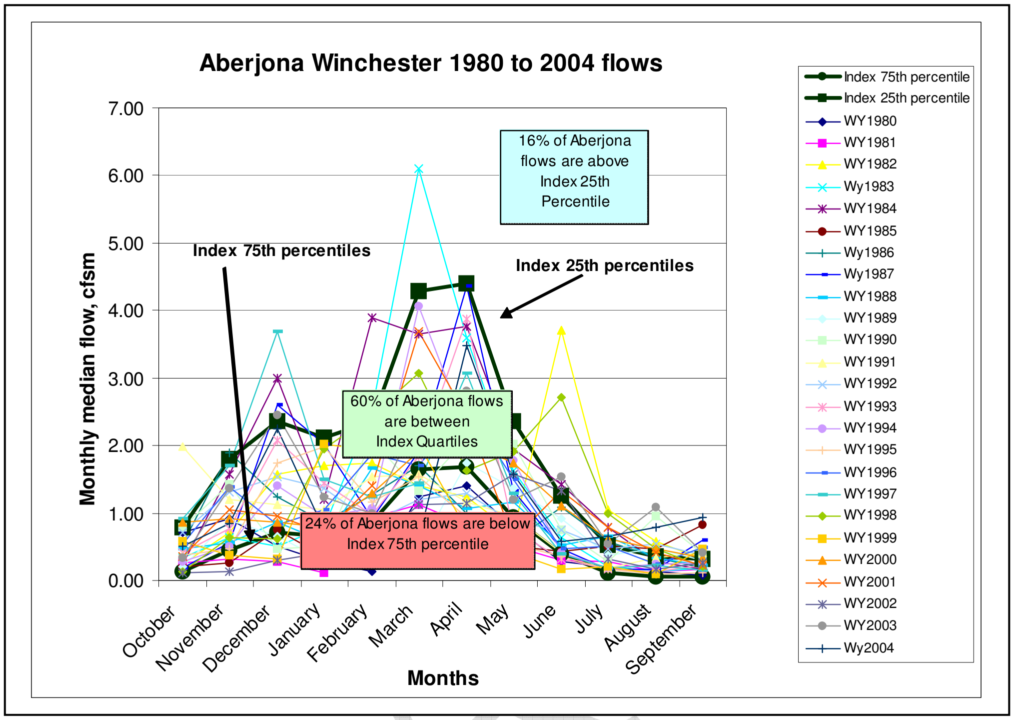
The annual target hydrograph could be used to evaluate whether significant flow alterations are present at a gage site that is not an index gage. This analysis is not appropriate for a short period of flow data, since the quartiles of index gage flow were developed with 45 years of variable weather and streamflow data. The analysis will not identify the causes of flow alterations, although the types of statistics that are most altered may provide insight as to the primary concerns in a basin.

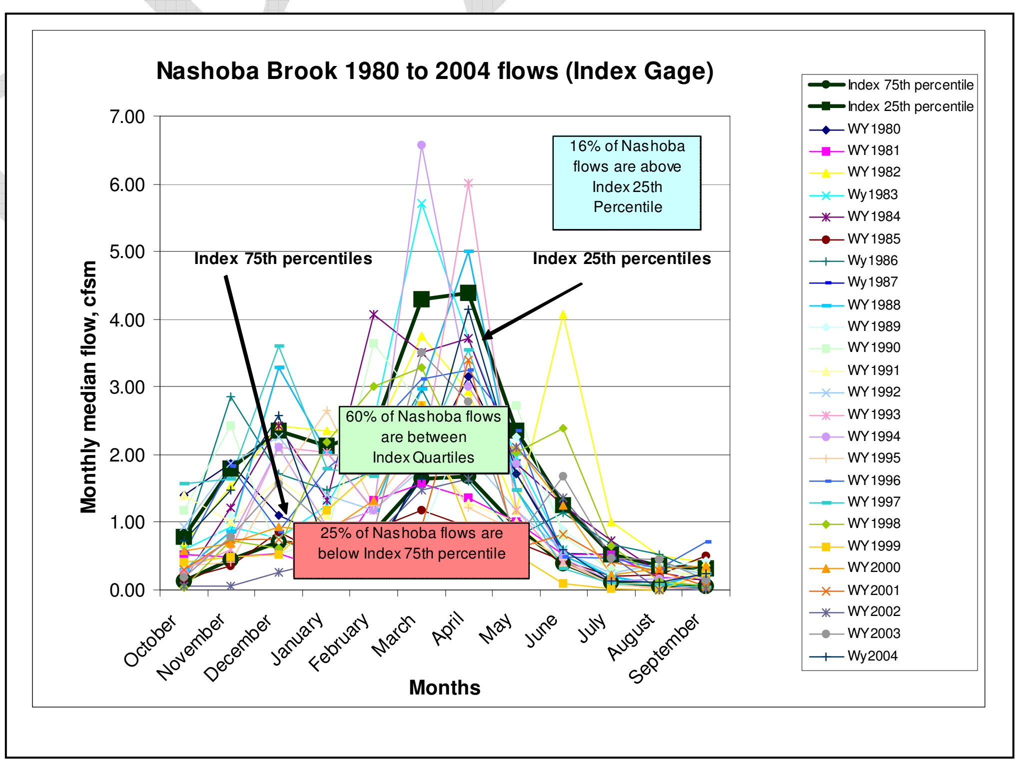
Example of Annual Target Hydrograph use: Compare how often a certain flow is within the interquartile range for an index and non-index gage for the same time period. An example is worked in Table 4.1, below. The most similar index gage was selected. The period from 1980 to 2004 was analyzed, to represent "modern" conditions. The quartiles of flow in cfsm from the index gage are known. The number of months that the monthly median non-index gage (Aberjona Winchester) and most similar index gage (Nashoba Brook Acton) flows falls within, below, and above the quartile flows during the period of interest are computed in an Excel spreadsheet (Appendix E), and summarized in Table 4.1. The analysis is shown schematically in Figure 4.

Table 4.1 Example of Annual Hydrograph Use

River	% of months Below Index Gage 75th percentile Exceedance Flow in cfsm	% of months Between Index Gage 25th and 75th percentile Exceedance Flow in cfsm	% of months Above Index Gage 25th percentile Exceedance Flow in cfsm
Aberjona Winchester (Non-Index Gage)	24 %	60 %	16 %
Nashoba Brook Acton (Index Gage)	25 %	59 %	16 %
Expected Normal	25 %	50 %	25 %

Figure 4.1. Schematic of Annual Hydrograph Use





The data show that during the years between 1980 and 2004, the statistics for both the index gage (Nashoba Brook) and the non-index gage (Aberjona) exhibited a distribution near that expected for flows (expected are 25% below the 75 percent flow duration, 50% within the 75th to 25th percentile, and 25% above the 25 percent flow duration). In fact, the distribution of flows for the two gages compared to the index quartiles is nearly exactly the same. Both gages exhibited fewer monthly flows above the 25th percentile index values than expected (16 percent actual compared to 25 percent expected), however, this is likely a result of climate conditions, as both gages show the same type of flow distribution.

4.2 ABF Flows:

ABF flows from an appropriate index gage could be used to establish monthly instream flow recommendations for a location, in the absence of existing flow data. Monthly ABF flows from the most appropriate index gage could be applied to an ungaged, non-index site in an effort to assure adequacy of flow and aquatic habitat suitability. As an example of ABF application, monthly target flows can be developed in accordance with the USFWS policy. As the policy states, the USFWS defaults to using the ABF minimum flow values, except when data is available from an existing USGS gage or a site-specific study is conducted. In this case, an estimated site-specific ABF is computed using the average of the median monthly flows from the most similar USGS index gage. Basin characteristics for the site of interest were determined and resulted in the selection of the Green River at Williamstown as an index gage. Using the average of the monthly median flows for the index gage, in cfsm, the flow values shown in Table 4.2 were selected for the subject location. The values were then translated into cfs for the location of interest, by multiplying the cfsm values by the drainage area for the location of interest.

Table 4.2 ABF Site-Specific Example: Average of the Median Monthly Flow for location of interest with drainage area 30 square miles, using index gage Green River at Williamstown.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Index Gage Flow, cfsm	1.61	1.53	3.34	4.33	2.23	1.14	0.62	0.44	0.50	0.76	1.74	1.81
Multiply by Area of Interest Drainage Area	30	30	30	30	30	30	30	30	30	30	30	30
Area of Interest Recommended Flow, cfs	48.3	45.9	100	130	66.9	34.2	18.6	13.2	15.0	22.8	52.2	54.3

A direct interpretation of the ABF policy results in a median August flow of 0.44 cfsm. The lowest flow during the fall/winter period (assumed to run from October to March) was 0.76 cfsm and the lowest spring flow (June) was 1.14 cfsm. These would also represent appropriate seasonal flow goals for the subject site.

4.3 IHA Flows:

The Indicators of Hydrologic Alteration software developed by The Nature Conservancy is most amenable to evaluating impacts of a discrete event such as construction of a dam on a river. However, the statistics generated from the program can also be used to demonstrate impacts on individual statistics such as low flows caused by upstream water withdrawals without return flows, or loss of high flows caused by the presence of flood control dams. When comparing flow statistics between two rivers, the data sets should be reduced to a cfsm basis, and the same years of data should be compared to the extent possible, otherwise climatological differences can skew the results. IHA statistics for index gages can be compared to non-index gages to determine the degree of flow alterations, and the statistics that are most significantly impacted. The most similar index gage should be compared to any given site, on a cfsm basis.

Richter, et al. (1997) developed five groups of IHA statistics. In general:

- Group 1 statistics describe monthly means
- Group 2 statistics describe minimums and maximums (for example, 7-day annual minimum flow, 90-maximum flow);
- Group 3 statistics describe timing of seasonal flows (Dates of annual minimum, maximum);
- Group 4 statistics describe occurrence and duration of low flow events;
- Group 5 statistics describe frequency and rates of flow rises and falls.

The IHA method and software are essentially designed to compare a single river that has been altered over time. The standard analysis involves inputting daily flow data and specifying a time period when alteration begins (the obvious example being dam construction). However, flow statistics for an impacted river can also be compared to an index river using the IHA method, when the statistics are compared on a unit drainage area basis (cubic feet per second per square mile of drainage area).

An example of comparing IHA statistics between a non-index gage and its most similar index gage is presented in Table 4.3. The analysis used the Aberjona River at Winchester gage (01102500) as a non-index gage, and compared it to the index gage selected as most similar (Nashoba Brook Acton, 01097300). The analysis shows that that the monthly winter flows (Group 1 statistics, November through May) at the non-index gage (Aberjona at Winchester) are slightly lower than those at the index gage (Nashoba). Conversely, summer flows at the Aberjona Winchester gage are significantly higher than at the Nashoba index gage. The extreme flow category (Group 2 statistics) confirms this finding, showing that the minimum flow statistics at the Aberjona Winchester gage are significantly higher than at the Nashoba index gage, while the maximum flow statistics at the Aberjona Winchester gage are slightly lower than at the Nashoba gage (on a cfsm basis). In parameter Group 3, the analysis shows that the timing of the annual maximum flows are quite different between the two sites: Julian day 81 (March 21) at the index gage, and Julian day 172 (June 21) at the Aberjona River at Winchester gage. The timing of the annual maximum flow typically corresponds with the spring flood season in southern New England. These statistical differences may suggest that some degree of flood storage may be occurring upstream of the Aberjona at Winchester gage, and that during the summer months there is some degree of flow augmentation. Flood control may be beneficial for public safety purposes; however, the natural aquatic community in this reach of the river and downstream of the flood storage impoundments may be impacted. Additionally, water supply withdrawals in the Aberjona basin upstream of the gage may be causing slightly lower winter flows, while the public water supply is augmented by water from the Massachusetts Water Resources Authority (MWRA) during the summer months, allowing higher summer recharge. Group 4 statistics indicate that the frequency of low flow pulses at the Aberjona River at Winchester gage is greater, based on the index gage comparison, although the duration of low pulses is less than at the index gage. Group 5 parameters show a higher rise rate for the Aberjona River than for the Nashoba, indicating that the Aberjona basin may be more flashy than the Nashoba, most likely as a result of impervious surfaces and development.

Table 4.3 Example of IHA Statistical Comparison between an Index Gage (Nashoba Brook Acton) and a Non-Index Gage (Aberjona River at Winchester), 1980-2004

	MEANS			
	Index	Non-Index		
	Nashoba	Aberjona	DEVIATION FACTOR	
	cfsm	cfsm	Magnitude	%
Parameter Group #1				
October	0.77	0.90	0.13	17%
November	1.36	1.21	-0.15	-11%
December	1.78	1.56	-0.22	-12%
January	1.87	1.39	-0.48	-26%
February	2.10	1.71	-0.39	-19%
March	3.51	2.45	-1.06	-30%
April	3.60	2.56	-1.04	-29%
May	1.89	1.43	-0.46	-24%
June	1.18	1.45	0.27	23%
July	0.44	0.69	0.25	57%
August	0.33	0.65	0.32	97%
September	0.36	0.63	0.27	75%
Parameter Group #2				
1-day minimum	0.04	0.10	0.06	150%
3-day minimum	0.05	0.12	0.07	140%
7-day minimum	0.06	0.13	0.07	117%
30-day minimum	0.13	0.24	0.11	85%
90-day minimum	0.31	0.43	0.12	39%
1-day maximum	16.86	18.44	1.58	9%
3-day maximum	13.81	13.55	-0.26	-2%
7-day maximum	10.00	8.85	-1.15	-12%
30-day maximum	5.33	4.21	-1.12	-21%
90-day maximum	3.46	2.68	-0.78	-22%
Number of zero days	0	0	0.00	0%
Base flow Index	0.04	0.10	0.06	150%
Parameter Group #3				
Date of minimum	245	256	11	4%
Date of maximum	81	172	91	112%

Notes:
Deviation Magnitude is the difference between the Index value and the Non-Index value for any statistic. A negative value indicates the Non-Index value is less than the Index value.
Percent Deviation is calculated as the Deviation Magnitude divided by the Index value.

Table 4.3 Example of IHA Statistical Comparison between an Index Gage (Nashoba Brook Acton) and a Non-Index Gage (Aberjona River at Winchester), 1980-2004 (continued)

	MEANS		DEVIATION FACTOR	
	Index	Non-Index		
	Nashoba	Aberjona		
	cfsm	cfsm	Magnitude	%
Parameter Group #4				
Low pulse count	6.13	13.60	7.47	122%
Low pulse duration	19.41	6.39	-13.02	-67%
High pulse count	7.89	9.20	1.31	17%
High pulse duration	4.64	2.83	-1.81	-39%
Low Pulse Threshold	0.32	0.37	0.05	16%
High Pulse Threshold	3.91	3.47	-0.44	-11%
Parameter Group #5				
Rise rate	0.64	0.91	0.27	42%
Fall rate	-0.32	-0.36	0.04	13%
Number of reversals	94	112	18	19%

Notes:

Deviation Magnitude is the difference between the Index value and the Non-Index value for any statistic. A negative value indicates the Non-Index value is less than the Index value.

Percent Deviation is calculated as the Deviation Magnitude divided by the Index value.

4.4 Site Specific Study

Establishment of the Index Streamflows does not preclude use of site specific studies to determine instream flow values. Properly designed and executed site-specific studies of instream flow needs are preferable to the use of Index Streamflows or can be used as a supplement to Index Streamflow statistics. Site-specific studies would include field work to examine the characteristics and flow needs of a specific river or river reach under investigation, and possibly flow needs of target fish communities for the river reach. Examples of site-specific studies that could be used in lieu of Index Streamflows to evaluate and establish appropriate instream flows are:

- Wetted Perimeter Method (Annear and Conder, 1984);
- R2 Cross (Espegren, 1998);
- Instream Flow Incremental Method (IFIM) and Physical Habitat Simulation Model (PHABSIM, Bovee, et al., 1998); and
- MesoHabSim (Parasiewicz, in press).

The Index Streamflows may be considered presumptive to characterize flows in ungaged rivers until other scientific evidence that increases knowledge of site-specific conditions is presented and accepted. Site-specific studies should be conducted by practitioners with experience and knowledge in the subject fields. It is suggested that if a site specific study is to be conducted, the scope of work for the study should be reviewed by any agency that would be making regulatory decisions based upon the results of the work. It may be beneficial to have an agency staff member and other stakeholders participate in a technical review committee as the study proceeds. This will help avoid subsequent disagreements about the applicability and adequacy of the study results.

4.4.1 Wetted Perimeter

Application of the wetted perimeter method is described, illustrated, and documented in Armstrong, et al. 2004, and Parker, et al., 2004 The method is based on the premise that there is a direct relation between the wetted perimeter in a riffle and fish habitat in streams (Annear and Conder, 1984; Lohr, 1993). The wetted perimeter of the stream is the width of the streambed and stream banks in contact with water for an individual cross section. Wetted-perimeter streamflow requirements are determined by analysis of field measurements of the cross section and wetted perimeter at different discharges (flows). In general, the objective of the wetted perimeter method is to identify a flow that maintains water over the entire streambed in a riffle (usually the shallowest point on a river). If water can be maintained in this location, the remainder of the river can be presumed to contain water, and connectivity along the river is assured (e.g., there will not be dry stretches of riverbed). The wetted perimeter method will only identify a flow at the low end of the hydrologic cycle that should be maintained for aquatic habitat protection. Wetted perimeter results will not represent the high flow needs of a river that would be expected in the spring, fall, and winter months.

In applications of the wetted perimeter method, plots of discharge versus wetted perimeter are developed for an individual cross section. At low flows, the wetted perimeter increases rapidly with increasing discharges. A plot of wetted perimeter versus discharge can be used to identify the point at which water fills the bottom of the streambed and rises within the stream banks. This creates a break in slope on the graph (Figure 4.2). Appendix 2 of Armstrong, et al. (2004) outlines the methodology for conducting the wetted perimeter assessment, Figure 9 in the text illustrates the methodology; and Appendix 3 provides additional detail of the application of the method in combination with hydraulic modeling. In practice, hydraulic modeling would not be necessary; the method could be accomplished with field measurements of the cross section at various flows. Optimally, a group of stakeholders could perform a site visit and identify the river reach of interest, as well as riffles, that would be targeted for the analysis. The resultant graphs of field measurements could be reviewed and the inflection points could be selected to identify an appropriate wetted perimeter flow.

Armstrong, et al. (2004) applied the wetted perimeter method to ten index gages, with results ranging from 0.13 to 0.58 cfsm and a median of 0.37 cfsm.

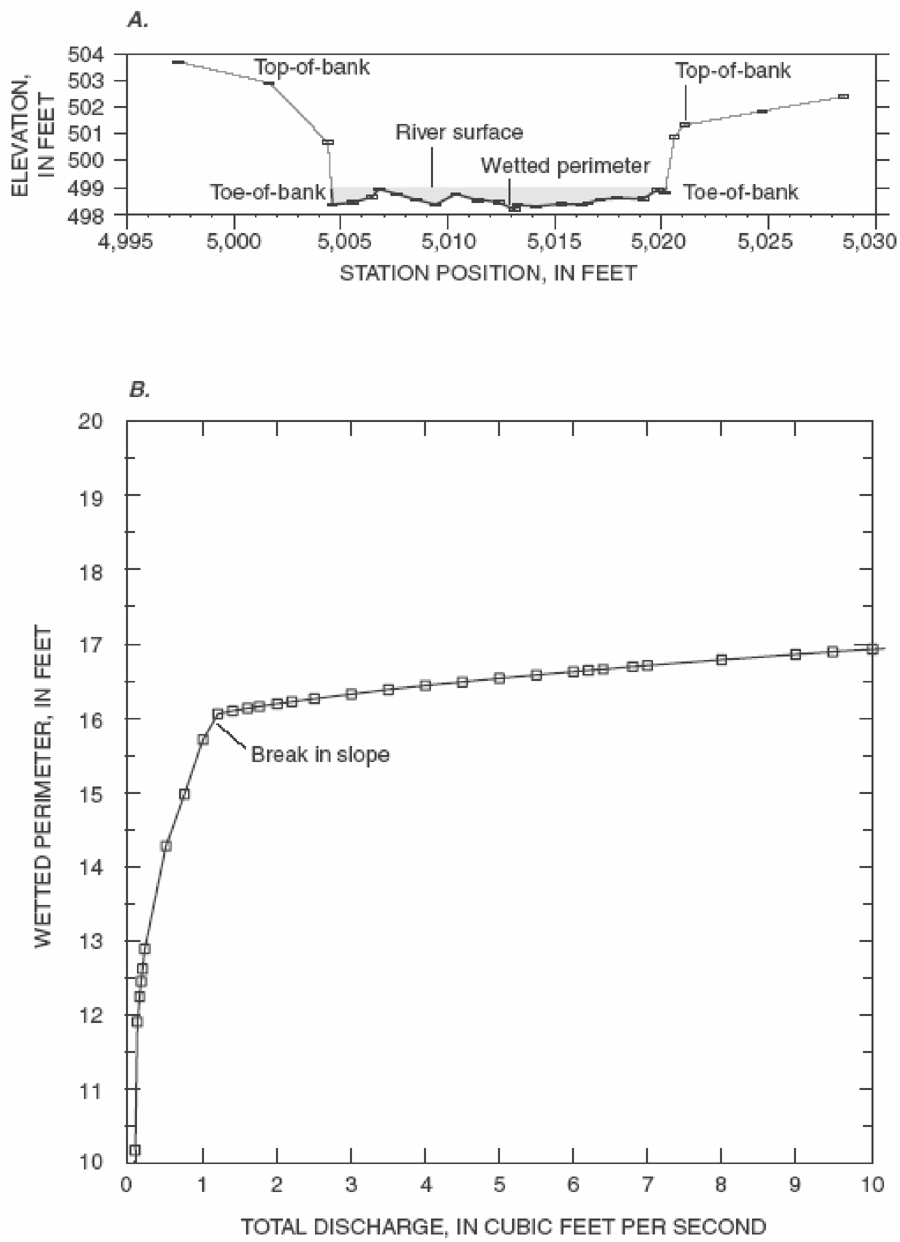


Figure 9. Schematic showing *A*, cross section of stream channel; and *B*, relation between wetted perimeter and discharge.

Figure 4.2 Wetted Perimeter Method Illustration (Armstrong et al., 2004)

4.4.2 R2Cross

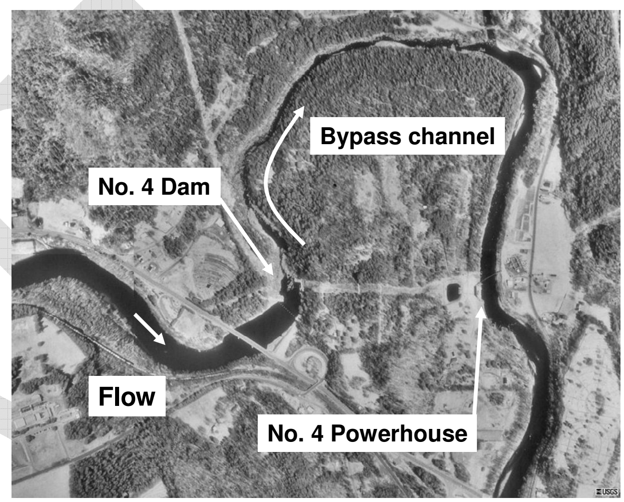
The R2Cross method is also summarized in Armstrong, et al. (2004). Like the wetted perimeter method, R2Cross was developed using the assumption that a discharge that maintains aquatic habitat in a riffle is sufficient to maintain habitat in nearby pools and runs for most life stages of fish and aquatic invertebrates (Nehring, 1979). However, this method is based upon three hydraulic parameters: mean depth, percent of bank-full wetted perimeter, and average water velocity. The criteria were developed in Colorado to quantify the streamflow needed to "preserve the natural environment to a reasonable degree" (Espegren, 1996). The depth criterion requires a mean depth that is at least one percent of the bankfull stream-top width, with a lower limit of 0.2 feet. The wetted-perimeter criterion requires a wetted perimeter that is at least 50 percent of the bank-full width (for streams less than 50 feet wide), equal to the top width (for streams between 51 and 60 feet wide), and 70 percent of the bank-full wetted perimeter for streams wider than 60 feet. The velocity criterion requires an average velocity of at least 1 cfs. The R2Cross method established different streamflow requirements for summer and winter seasons. Summer R2Cross criteria in Colorado represent the high-flow season and would reasonably be reversed to represent winter flows in Massachusetts. In Colorado, the winter R2Cross criteria are based upon streamflow that meets any two of the three hydraulic criteria. In Massachusetts, this would be applied to the summer months when lower flows are experienced. Application of the "three of three" R2Cross criteria may not result in reasonable streamflows for Massachusetts, based upon analyses by USGS.

Armstrong et al. (2004) applied the R2Cross method to ten index gages, with a result of 0.16 to 0.85 cfsm (for the summer or 2-of-3 criteria application) and 0.39 to 2.1 cfsm for winter months (meeting 3-of-3 criteria). Meeting the mean velocity criterion of 1 ft/second was often the limiting variable in determining streamflow thresholds. The applications are documented in Appendix 3 of Armstrong, et al. (2004). Additional documentation is available in Parker, et al., 2004. USGS performed hydraulic modeling to establish the target streamflows that would meet R2Cross criteria; however, in application, a series of field measurements of stage and discharge at properly selected riffles could suffice to establish the target streamflows without modeling.

4.4.3 Instream Flow Incremental Method (IFIM) and Physical Habitat Simulation Model (PHABSIM)

The Instream Flow Incremental Method (IFIM) was developed by an interdisciplinary team under leadership of the US Fish & Wildlife Service and is currently supported by the USGS at its Fort Collins, Colorado Science Center. Information about the IFIM can be found in Bovee, et al., 1998. The Instream Flow Incremental Methodology is a framework for approaching various issues related to developing an instream flow policy to meet the needs of the aquatic ecosystem while considering riverine habitat-flow relationships, timing of flow events, institutional arrangements, and water supply. The methodology can support comparisons of numerous alternative water management scenarios. The IFIM is a standard procedure commonly used in hydropower licensing under the Federal Energy Regulatory Commission (FERC) and is also accepted by the US Fish & Wildlife Service (USFWS) as a site-specific evaluation tool. IFIM is composed of a library of linked analytical procedures that describe the spatial and temporal features of aquatic habitat from given river regulation alternatives. In general, the methodology incorporates study design, stakeholder input, field data collection, hydraulic flow modeling, application of habitat suitability indices (HSI) for target aquatic organisms at various life stages, completion of a Physical Habitat Simulation System (PHABSIM) model, calculation of areas of aquatic habitat, development of graphs of flow and habitat time series, and evaluation of various proposed flow regimes for habitat quantity and quality. The method provides a graduated scale of habitat at different flows, and the user or stakeholder group makes a decision regarding flow recommendations based on negotiations around this incremental scale.

The following example of an IFIM was associated with an application for instream flow needs at a hydroelectric facility on the Deerfield River (provided by Gomez and Sullivan Engineers).



The Deerfield River Basin is located in southern VT and northern MA and drains into to the Connecticut River near East Greenfield, MA. There are 10 dams located on the Deerfield River mainstem that produce hydroelectric power. Most of the dams impound water that is conveyed through a penstock or fore bay to a powerhouse located further downriver. The diverted water is returned to the river after it flows through turbines contained within the powerhouse. Depending on the each dam's local topography, there can be several hundred feet or miles (in the case of penstocks) between the dam and powerhouse, often leaving a dry stretch of the Deerfield River during low flow periods. Historically, spillage below the dam occurred only when the hydraulic capacity of the turbines was exceeded. The dry stretch, between the dam and powerhouse, is referred to as a "bypass reach".

In the early 1990s the owners of the dam (the Licensee) were required to relicense the facilities with the Federal Energy Regulatory Commission (FERC). Among many environmental concerns was the lack of flow in the bypass reaches during various times of the year. Thus, studies were conducted to determine the magnitude and seasonal flows needed in the bypass reaches for the protection of aquatic resources. In addition, studies were required below the powerhouses for those projects that operated in a peaking mode, where the magnitude of discharge from the powerhouse can vary over a short time period. These peaking discharges can impact aquatic habitat below the powerhouse.

To determine flows needed in the bypass to protect aquatic resources, field data coupled with hydraulic/habitat modeling was used. The Physical Habitat Simulation Model (PHABSIM) was used to develop a relationship between streamflow and physical habitat for various life stages and species of fish. The basic objective of physical habitat simulation is to obtain a representation of the physical stream so that the stream may be linked, through biological considerations, to the social, political, and economic world.

The two basic components of PHABSIM are the hydraulic and habitat simulations of a stream reach using defined hydraulic parameters and habitat suitability criteria. Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity, and substrate as a function of flow. This information is used to calculate a habitat measure called Weighted Usable Area for the stream segment from suitability information based on field sampling of the various species of interest. Habitat Suitability Index (HSI) curves are used to determine the preference a given fish and life stage has for depth, velocity and substrate. An HSI value of 1 is optimal habitat, while an HSI value of 0 represents no habitat. For example, an adult brook trout's ideal habitat for depth may be 2 feet- thus the HSI value for 2 feet would be 1.

In the case of the Deerfield River, habitat mapping was conducted in each of the bypass reaches and the characteristics of each habitat unit (riffles, runs, pools) were recorded. Characteristics recorded included velocity, depth, overhead cover, instream cover, undercut banks, snags and other factors influencing habitat use. From these data, representative transects were identified and placed at various locations in the bypass reaches. A total of three flow data sets, ranging from low to high flows, were collected at each transect. Data sets included the collection of depth and velocity data at "cells" along each transect as well as substrate information. In addition to the depth and velocity data, the water surface profile at each transect and flow was measured.

Using the depth and velocity and water surface profile information for each transect, three hydraulic models were developed for each flow. The value of the hydraulic model is the ability to predict depth and velocities at each transect for flows below and above those physically measured in the field. Typically, the depths and velocity data in the hydraulic model can be extrapolated between 40-250% of the measured flow. Thus, if the measured flow, including depths and velocities, was 100 cfs, the hydraulic model can be used predict depths and velocities at 40 cfs and 250 cfs. Having collected full data at three flows the full range of flows can be simulated. The hydraulic models were calibrated to measured water surface elevations and cellular velocities.

Once the hydraulic model was calibrated, habitat modeling was conducted. Using the depth, velocity and substrate data, coupled with the HSI data, habitat was quantified. Graphs of flow versus habitat (commonly called Weighted Useable Area graphs) were developed for each species and life stage of fish, and in some cases, macroinvertebrates. The target species were smallmouth bass, rainbow trout, walleye, sturgeon, landlocked salmon and others.

Using Weighted Useable Area (WUA) versus flow curves for the various species and life stages of fish, seasonal flow recommendations were made to protect habitat requirements throughout the year. Various analyses of the WUA versus flow curves were conducted to develop final flow recommendations below each of the dams. For those projects where PHABSIM was applied below a peaking hydropower project, additional analyses were conducted. The WUA versus flow curves were linked with hourly discharges from the powerhouse to develop habitat time series plots. These plots displayed how the habitat fluctuates when powerhouse discharges fluctuate over small time increments. Similarly habitat duration curves (similar to flow duration curves) were developed for each species and life stage.

The final result was the establishment of flows below each dam and modifications to peaking operations at some projects.

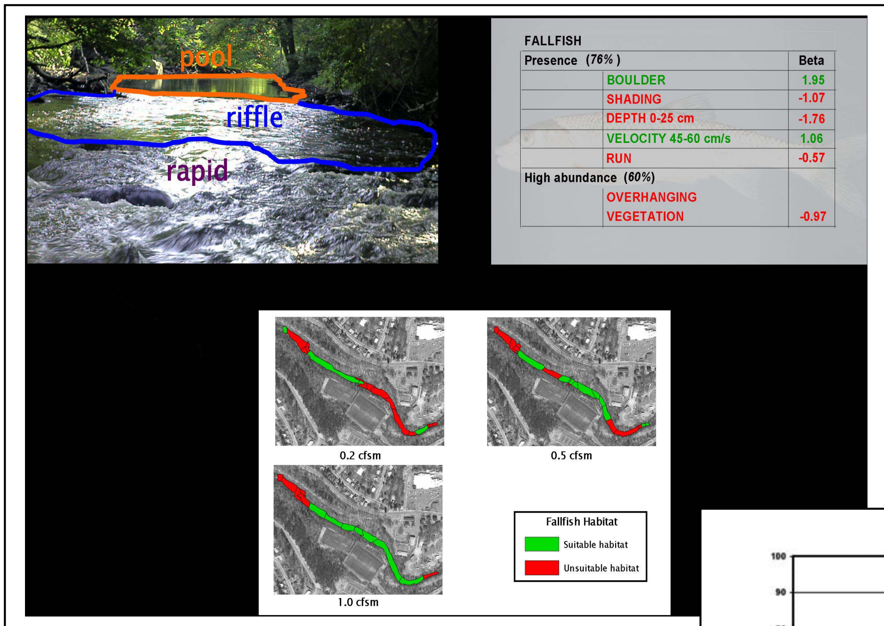
4.4.4 MesoHABSIM

The Mesohabitat Simulation Model (MesoHABSIM), developed by the Northeast Instream Habitat Program at the University of Massachusetts in Amherst addresses the requirements of watershed-based management of running waters. It builds upon pre-existing physical habitat simulation models (e.g. Physical Habitat Simulation model, PHABSIM) to predict an aquatic community's response to habitat modification. MesoHABSIM was initially developed during a restoration study on the Quinebaug River in Massachusetts. The changing spatial distributions of physical attributes of a river as a result of variations in flow and the biological responses of aquatic species to these changes, provide the basis for simulating the consequences of ecosystem alteration, and consequently the justification of restoration measures. MesoHABSIM modifies the data acquisition technique and analytical approach of similar models by changing the scale of resolution from micro- to meso-scales. The MesoHABSIM model takes variations in stream morphology along the river into account and is more applicable to large-scale issues. The MesoHABSIM method applies habitat and fish measurements at larger spatial units than the IFIM/PHABSIM method and is therefore applicable for river scale, site specific studies. Elements of MesoHABSIM are illustrated in Figure 4.3.

In the MesoHABSIM method, mesohabitat types are defined by their hydromorphological units (HMUs), such as pools and rapids, geomorphology, land cover and other hydrological characteristics. Mesohabitats are mapped under multiple flow conditions at extensive sites along the river. Fish data are collected in randomly distributed mesohabitats where habitat surveys are also conducted. This allows modeling of available fish habitat at a range of flows. Rating curves represent the changes in relative area of suitable habitat in response to flow and allow for the determination of habitat quantity at any given flow within the range of surveys. Rating curves can also be used to evaluate the benefits of various restoration measures on the entire fish community. In combination with hydrologic time series, rating curves are used to create Uniform Continuous-Under-Threshold (UCUT) curves for the analysis of frequency, magnitude and duration of significant habitat events. The UCUT curve technique modified from Capra et al. (1995) helps define critical thresholds and determine what habitat variability and availability is necessary to support the target river fauna. UCUT curves evaluate durations of unsuitable habitat under a specified threshold by comparing continuous durations in days under this threshold to the cumulative durations in the study period. A useful product of the UCUT curves are reference tables and seasonal Assessment of Cumulative Threshold Nomogram (ACTogram) that managers can use to determine needs for conservation actions depending on how long a fish community can tolerate unsuitable flow conditions depending on its life stage. Instream flow prescriptions created with help of this approach are of dynamic nature, follow therefore, the principles of the natural flow paradigm and allow for more effective use of water resources than standard minimum flow procedures.

To use physical habitat models to analyze and predict ecosystem potential, the composition of the native fish community is determined and subset of species (Target Fish Community) are selected for model development and analysis. Securing habitat for naturally occurring dominant species should preserve the most profound characteristics of the ecosystem, providing survival conditions for the majority of the aquatic community and therefore a reference for restoration efforts. Since habitat availability forms the structure of aquatic fauna, the affinity between the structure of the river habitat and the structure of the fish community can be used as a measure of habitat quality.
The results of MesoHABSIM create the framework for integrative analyses of many aspects of the ecosystem. It also allows managers to recreate reference conditions and evaluate possible instream and watershed restoration measures or alterations, such as dam removals or changes in water withdrawals. From the perspective of resource managers, it not only allows for quantitative measures of ecological integrity, but also creates a basis for making decisions where trade-offs between resource use and river restoration need to be considered.

The MesoHABSIM model has recently been applied to the Souhegan River in New Hampshire for the New Hampshire Department of Environmental Services to establish recommended streamflows protective of specified instream flow needs. The report for this project can be accessed at the web site: http://www.unh.edu/erg/souhegan/



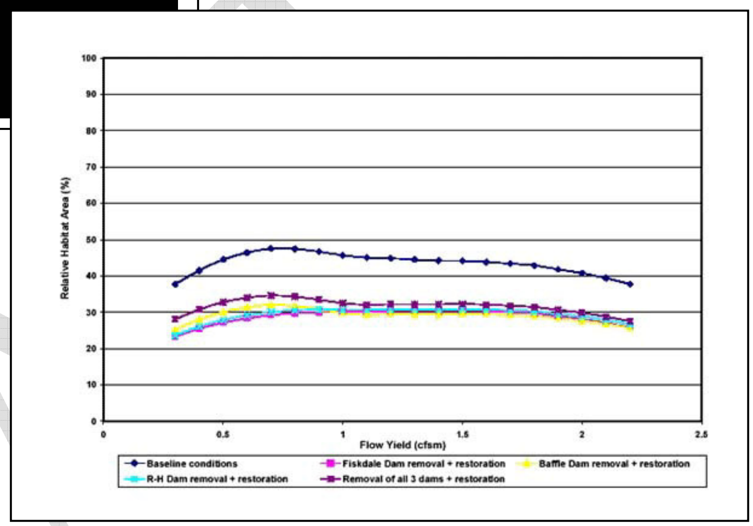
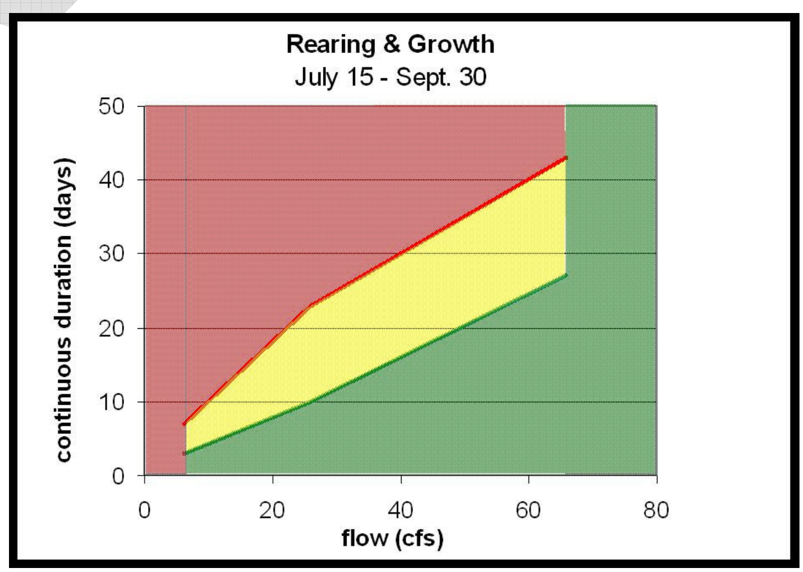


Figure 4.3 Example Elements of the MesoHabSim model

		Typical	Critical	Minimum
Apr 16-May25 Shad Spawning	*Habitat (%)*	54	51	45
	Duration below triggering catastrophe (days)	37	31	28
	Allowable duration below (days)	30	25	20
	Duration pulse (days)	2	2	2
May 26-Jul 7 Target Species Spawning	*Habitat (%)*	-	-	90
	Duration below triggering catastrophe (days)	-	-	15
	Allowable duration below (days)	-	-	6
	Duration pulse (days)	-	-	2
Jul 8-Sep 15 Rearing & Growth	*Habitat (%)*	36	26	24
	Duration below triggering catastrophe (days)	32	15	10
	Allowable duration below (days)	18	10	5*
	Duration pulse (days)	2	2	2
Sep 16-Oct 15 Overlap	*Habitat (%)*	51 / 36	48 / 26	45 / 24
	Duration below triggering catastrophe (days)	40 / 32	30 / 15	23 / 10
	Allowable duration below (days)	40 / 18	25 / 10	20 / 5
	Duration pulse (days)	3 / 2	4 / 2	/ 2
Oct 16- Nov 30 Salmon Spawning	*Habitat (%)*	51	48	45
	Duration below triggering catastrophe (days)	40	30	23
	Allowable duration below (days)	40	25	20*
	Duration pulse (days)	3	3	4
Dec 1-Feb 28/29 Winter Survival	*Flow*	2.5 cfsm	-	2.0 cfsm
	Duration below triggering catastrophe (days)	45	-	45
	Allowable duration of below (days)	35	-	15
	Duration pulse (days)	2	-	2



5.0 Ongoing Research and Refinements of Massachusetts Index Streamflows

The Index Streamflows described in this document are intended to be used in the interim until additional studies, currently underway, are completed. The results of ongoing research will provide additional resources to draw upon, which will make determination of Index Streamflows more robust and provide the ability to more accurately link biological relevance to instream flow requirements.

5.1 USGS Flow and Habitat Pilot Study

The USGS in cooperation with the Massachusetts Department of Conservation and Recreation and the Department of Environmental Protection (MassDEP) is undertaking additional research to evaluate the impacts of flow alteration, land use, and water quality on the fish community composition in three Massachusetts basins. The three basins (Ipswich, Blackstone, and Sudbury/Assabet) have been the subject of USGS modeling in recent years. The Hydrologic Simulation Program-Fortran (HSPF) model has been applied to each of the basins. The modeling provides simulated natural streamflows, in the absence of human water withdrawals and wastewater return flows. The three basins also include a range of conditions between minimally altered and severe flow alterations. An "urban index" will be calculated for each of the subbasins, based on road density, percentage of non-forest land in stream buffers, percentage of watershed developed, and population density. Simulated "pre-impact" and "post-impact" river flow data and statistics will be analyzed to quantify and classify the degree of flow alteration experienced in each of the subbasins. This data will be combined with fish community data from Massachusetts Division of Fisheries and Wildlife's database to arrive at fish community distributions. Statistical techniques will be applied to the data to determine and document relationships between flow alterations and the composition of fish communities in each of the sub-basins modeled, and to determine whether or not there is a degree of land use or flow alteration above which fish community integrity is significantly degraded. The results of this research are expected to provide insight into the interrelations between land use, water quality, streamflow alteration, and biological integrity. The results of this work may assist in establishment of limitations of hydrologic alteration that would be protective of biological integrity. This study is ongoing and results are expected to be presented to cooperators (and the public at a WRC meeting) in 2008. If the pilot study results appear promising, the work could be expanded to a wider area, potentially statewide.

5.2 Sustainable Yield Estimator

USGS in cooperation with MassDEP is developing a screening level computer application to assess the effects of water withdrawals and wastewater returns on streamflow in Massachusetts. The Sustainable Yield Estimator (SYE) will generate a synthesized natural hydrograph, and an estimated impacted hydrograph for most mainland Massachusetts locations by point-and-click selection. The SYE will also have the ability to compare synthesized daily streamflows to user-specified instream flow targets. While the SYE tool will not replace Index Streamflows, it will provide a useful tool in its ability to generate natural and estimated impacted hydrographs (and thus streamflow statistics) for ungaged locations in Massachusetts. Statistics generated from the SYE will likely replace the existing equations in the USGS Massachusetts StreamStats on-line application to estimate natural streamflows in Massachusetts. The benefits of the SYE statistics over the existing StreamStats are that the SYE covers the entire hydrograph while StreamStats focuses on the lower end of the flow duration curve only; and that SYE will generate a time-series hydrograph, while StreamStats only provides flow duration curve point estimates. Thus, the SYE tool may become useful in refining natural flows in Massachusetts and improve our ability to compare impacted flows to natural flows, and assess river integrity. The SYE database also contains a plethora of information that could be developed into other useful water resources management tools.

5.3 Basin Stress Reclassification

The Index Streamflows presented herein, and the Sustainable Yield Estimator (SYE) tool are currently being used by WRC in the next phase of basin stress reclassification in Massachusetts. DCR has been working with USGS through the Cooperative Program to assess the degree of hydrologic alteration in small sub-basins of Massachusetts using the SYE model. The exact methodology for Stressed Basins reclassification has not yet been determined,however, a Task Force has been meeting since the Fall of 2007. Preliminary work with the Task Force and USGS indicates that flow alteration statistics, along with water quality, and target fish community data will form the basis of Basin Stress Reclassification in Massachusetts. Results of the USGS study will include assessment and mapping of flow alteration, water quality, and target fish communities in Massachusetts. Publication of a Scientific Investigations Report is expected in February 2009.

Table 2.1 Summary of Index Gages and Drainage Area Characteristics

USGS Gage #	Gage Name	Drainage Area $Miles^2$ (1)	Mean Basin Slope, % (2)	Stratified Drift per Stream Length (mi^2/mi) (2)	Region (0 or 1) (3)
01174900	Cadwell Creek Belchertown, MA	2.55	9.44	0.0040	1
01174000	Hop Brook New Salem, MA	3.39	10.61	0.0079	1
01093800	Stony Brook Tributary Temple, NH	3.60	16.59	0.0135	1
01118300	Pendleton Hill Brook Clarks Falls, CT	4.02	6.47	0.0651	0
01105600	Old Swamp River Weymouth, MA	4.50	3.11	0.1420	0
01115098	Peeptoad Brook Westerly, RI	4.96	6.94	0.1028	0
01100700	East Meadow River Haverhill, MA	5.47	5.59	0.2312	0
01171800	Bassett Brook Northampton, MA	5.56	9.44	0.1909	1
01195100	Indian River Clinton, CT	5.68	7.44	0.0198	0
01085800	W Branch Warner River Bradford, NH	5.91	17.27	0.0065	1
01187400	Valley Brook West Hartland, CT	7.03	14.55	0.0415	1
01331400	Dry Brook Adams, MA	7.67	11.92	0.0212	1
01106000	Adamsville Brook Adamsville, RI	8.01	2.82	0.0038	0
01115630	Nooseneck River Nooseneck, RI	8.23	6.18	0.2786	0
01175670	Sevenmile River Spencer, MA	8.81	7.86	0.0418	1
01117468	Beaver River Usquepaug, RI	8.87	6.70	0.1872	0
01184100	Stony Brook West Suffield, CT	10.4	6.35	0.1140	1
01165500	Moss Brook Wendell Depot, MA	12.1	10.49	0.1182	1
01073000	Oyster River Durham, NH	12.1	4.37	0.0130	0
01174565	W Branch Swift River Shutesbury, MA	12.6	11.17	0.0819	1
01097300	Nashoba Brook Acton, MA	12.8	4.67	0.2135	0

Notes: (1) Source of Drainage Areas is USGS (2007), Table 1.
(2) Source of Drainage Area Characteristics is USGS (2007), Table 3.
(3) Source of Region data is USGS WRIR 00-4135 and DCR estimation for out of state gages.

Table 2.1 Summary of Index Gages and Drainage Area Characteristics (continued)

USGS Gage #	Gage Name	Drainage Area Miles^2 (1)	Mean Basin Slope, % (2)	Stratified Drift per Stream Length (mi^2/mi) (2)	Region (0 or 1) (3)
01115187	Ponaganset River South Foster, RI	13.7	5.03	0.0598	0
01111300	Nipmuc River Harrisville, RI	16.0	5.27	0.1148	0
01126600	Blackwell Brook Brooklyn, CT	17.0	7.13	0.0339	0
01161500	Tarbell Brook Winchendon, MA	17.8	6.32	0.0436	1
01162500	Priest Brook Winchendon, MA	19.4	6.73	0.0585	1
01187300	Hubbard River W Hartland, CT	19.9	8.74	0.0018	1
01194500	E Branch Eightmile River N Lyme, CT	22.4	6.76	0.0395	0
01169900	South River Conway, MA	24.1	14.91	0.0616	1
01121000	Mount Hope River Warrenville, CT	28.6	7.49	0.0146	0
01199050	Salmon Creek Lime Rock, CT	29.4	12.77	0.0701	1
01123000	Little River Hanover, CT	30.0	7.01	0.0521	0
01105730	Indian Head River Hanover, MA	30.3	2.44	0.2509	0
01095220	Stillwater River Sterling, MA	31.6	8.17	0.1039	0
01117800	Wood River Arcadia, RI	35.2	6.4	0.2074	0
01332000	N Branch Hoosic River N Adams, MA	40.9	17.02	0.0321	1
01170100	Green River Colrain, MA	41.4	16.92	0.0114	1
01333000	Green River Williamstown, MA	42.6	24.33	0.0571	1
01109000	Wading River Norton, MA	43.3	3.04	0.2909	0
01198500	Blackberry River Canaan, CT	43.8	11.41	0.0751	1
010965852	Beaver Brook N Pelham, NH	47.8	5.37	0.0351	0
01198000	Green River Great Barrington, MA	51.0	14.08	0.0593	1
01171500	Mill River Northampton, MA	54.0	11.55	0.0805	1

Notes: (1) Source of Drainage Areas is USGS (2007), Table 1.
(2) Source of Drainage Area Characteristics is USGS (2007), Table 3.
(3) Source of Region data is USGS WRIR 00-4135 and DCR estimation for out of state gages.

Table 2.1 Summary of Index Gages and Drainage Area Characteristics (continued)

USGS Gage #	Gage Name	Drainage Area Miles^2 (1)	Mean Basin Slope, % (2)	Stratified Drift per Stream Length (mi^2/mi) (2)	Region (0 or 1) (3)
01084500	Beard Brook Hillsboro, NH	55.3	12.06	0.0089	1
01096000	Squannacook River W Groton, MA	63.7	7.97	0.1318	0
01082000	Contoocook River Peterborough, NH	68.1	8.27	0.0186	1
01154000	Saxtons River Saxtons River, VT	72.1	18.72	0.0361	1
01118000	Wood River Hope Valley, RI	72.4	6.42	0.1854	0
01120000	Hop Brook Columbia, CT	73.9	6.83	0.0428	0
01089000	Soucook River Concord, NH	76.8	7.61	0.0238	1
01155000	Cold River Drewsville, NH	83.3	13.23	0.0049	1
01169000	North River Shattuckville, MA	89.0	14.87	0.0296	1
01111500	Branch River Forestdale, RI	91.2	6.28	0.1364	0
01181000	W Branch Westfield Huntington, MA	94.0	13.68	0.0246	1
01117500	Pawcatuck River Wood River Junction, RI	100	4.61	0.3147	0
01193500	Salmon River E Hampton, CT	100	7.57	0.0494	0
01091000	S Branch Piscataquog River Goffstown, NH	104	9.71	0.0417	1
01176000	Quaboag River West Brimfield, MA	150	7.97	0.0708	1
01200000	Ten Mile River, CT	203	12.63	0.0469	1
01108000	Taunton River Bridgewater, MA	261	2.59	0.2539	0
01118500	Pawtucket River Westerly, RI	295	5.32	0.2277	0

Notes: (1) Source of Drainage Areas is USGS (2007), Table 1.
(2) Source of Drainage Area Characteristics is USGS (2007), Table 3.
(3) Source of Region data is USGS WRIR 00-4135 and DCR estimation for out of state gages.

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01093800	Stony Brook Trib Temple, NH	0.67 1.06 1.78	0.75 1.08 1.94	1.22 2.40 4.56	2.42 3.89 6.94	1.19 1.89 3.06	0.39 0.75 1.44	0.13 0.25 0.53	0.09 0.17 0.36	0.09 0.19 0.39	0.22 0.47 1.11	0.64 1.31 2.36	0.81 1.39 2.44
01174900	Cadwell Creek Belchertown, MA	0.94 1.33 2.31	0.96 1.53 2.51	1.69 2.75 4.71	1.88 2.86 4.74	1.25 1.85 2.84	0.39 0.78 1.74	0.14 0.31 0.69	0.10 0.24 0.55	0.09 0.20 0.51	0.24 0.51 1.37	0.67 1.33 2.39	0.94 1.61 2.55
01174000	Hop Brook New Salem, MA	0.82 1.30 2.35	0.91 1.39 2.49	1.56 2.65 4.56	2.09 3.21 5.31	1.13 1.83 2.78	0.46 0.88 1.68	0.13 0.29 0.66	0.06 0.19 0.44	0.05 0.14 0.32	0.18 0.35 0.97	0.47 1.07 1.95	0.77 1.39 2.74
01118300	Pendleton Hill Brook, CT	1.37 2.14 3.48	1.42 2.35 3.73	2.11 2.99 4.48	1.97 2.99 4.48	1.39 2.06 2.99	0.50 0.95 1.77	0.13 0.30 0.67	0.08 0.20 0.50	0.09 0.20 0.55	0.27 0.50 1.00	0.70 1.27 2.49	1.24 2.11 3.73
01105600	Old Swamp R Weymouth, MA	1.07 1.60 2.67	1.22 1.82 2.89	1.67 2.44 4.00	1.44 2.04 3.43	1.02 1.44 2.16	0.40 0.71 1.31	0.14 0.27 0.56	0.11 0.24 0.56	0.13 0.24 0.56	0.29 0.53 1.02	0.73 1.21 2.16	1.00 1.56 2.67
01100700	E Meadow River Haverhill, MA	0.86 1.43 2.46	1.00 1.71 2.87	1.93 3.50 6.22	2.46 4.10 6.97	1.31 2.11 3.53	0.51 0.90 1.75	0.22 0.37 0.66	0.14 0.24 0.44	0.14 0.20 0.39	0.22 0.39 0.84	0.51 1.31 2.44	0.86 1.60 3.02
01115098	Peeptoad Brook Westerly, RI	1.21 1.99 3.56	1.44 2.42 4.00	2.34 3.45 5.75	2.02 3.25 5.03	1.21 1.83 2.75	0.36 0.75 1.68	0.11 0.22 0.53	0.08 0.19 0.43	0.08 0.16 0.38	0.14 0.32 0.85	0.46 1.10 2.27	0.93 1.88 3.66
01171800	Bassett Brook Northampton MA	0.69 1.08 1.62	0.81 1.21 1.83	1.32 2.28 3.53	1.65 2.52 3.97	1.03 1.52 2.28	0.49 0.75 1.37	0.25 0.39 0.66	0.18 0.31 0.57	0.20 0.30 0.53	0.28 0.47 0.98	0.49 1.03 1.77	0.71 1.20 1.94
01195100	Indian River Clinton, CT	1.00 1.64 2.67	1.07 1.75 2.85	1.58 2.31 3.56	1.46 2.25 3.46	1.00 1.52 2.44	0.28 0.62 1.25	0.08 0.17 0.41	0.06 0.12 0.30	0.05 0.12 0.34	0.14 0.32 0.68	0.48 0.96 1.96	0.89 1.56 2.85
1085800	W Br Warner R Bradford, NH	0.54 0.76 1.29	0.56 0.83 1.42	0.97 1.86 3.90	2.54 4.24 7.97	1.17 2.03 3.46	0.31 0.61 1.27	0.11 0.22 0.46	0.08 0.15 0.32	0.08 0.15 0.34	0.20 0.44 1.14	0.58 1.31 2.37	0.78 1.20 2.03
01187400	Valley Brook W Hartland, CT	0.78 1.16 1.91	0.77 1.22 2.05	1.46 2.54 4.44	1.76 2.98 5.54	1.01 1.62 2.79	0.32 0.62 1.46	0.13 0.27 0.57	0.09 0.18 0.44	0.09 0.20 0.50	0.21 0.50 1.26	0.72 1.32 2.54	0.89 1.49 2.59
01331400	Dry Brook Adams, MA	0.58 0.98 1.80	0.61 0.98 1.89	1.22 2.33 4.82	2.36 4.16 7.34	1.06 1.86 3.42	0.41 0.79 1.59	0.18 0.33 0.65	0.13 0.23 0.58	0.11 0.23 0.61	0.21 0.54 1.33	0.65 1.34 2.47	0.83 1.44 2.66

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:

75th percentile flow
50th percentile flow
25th percentile flow

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01106000	Adamsville Brook Adamsville, MA	1.79 2.87 5.33	2.01 3.33 5.74	2.87 4.47 7.19	2.46 4.03 6.72	1.79 2.61 4.47	0.61 1.27 2.46	0.10 0.31 0.84	0.05 0.19 0.70	0.07 0.20 0.67	0.25 0.61 1.49	0.91 1.71 3.56	1.64 2.77 5.74
01115630	Nooseneck River Nooseneck, RI	1.59 2.42 3.49	1.90 2.80 3.97	2.56 3.32 4.64	2.48 3.35 4.67	1.78 2.39 3.19	0.94 1.39 2.21	0.47 0.70 1.12	0.35 0.56 0.94	0.36 0.56 0.82	0.49 0.79 1.34	0.96 1.52 2.54	1.47 2.20 3.54
01175670	Sevenmile River Spencer, MA	0.84 1.36 2.27	0.95 1.48 2.38	1.59 2.61 4.09	1.93 2.89 4.65	1.11 1.70 2.50	0.50 0.85 1.59	0.15 0.35 0.69	0.08 0.22 0.45	0.06 0.17 0.41	0.18 0.40 0.94	0.45 0.91 1.82	0.82 1.48 2.50
01117468	Beaver River Usquepaug, RI	1.71 2.48 3.68	1.92 2.82 3.95	2.59 3.47 4.74	2.70 3.61 4.96	2.03 2.71 3.61	1.17 1.69 2.59	0.60 0.88 1.35	0.40 0.61 1.00	0.36 0.59 0.89	0.47 0.70 1.22	0.78 1.35 2.37	1.38 2.16 3.49
01184100	Stony Brook W Suffield, CT	0.66 1.02 1.90	0.71 1.23 2.28	1.34 2.34 4.10	1.52 2.56 4.94	0.80 1.33 2.30	0.26 0.53 1.29	0.09 0.22 0.47	0.06 0.14 0.36	0.08 0.17 0.42	0.20 0.44 1.07	0.55 1.07 1.99	0.75 1.23 2.30
01165500	Moss Brook Wendell, MA	0.57 0.93 1.66	0.64 1.07 1.79	1.07 2.04 3.87	1.81 3.05 5.07	0.91 1.48 2.47	0.34 0.68 1.36	0.15 0.27 0.57	0.10 0.21 0.47	0.11 0.21 0.46	0.22 0.40 0.99	0.47 0.96 1.73	0.59 1.15 2.01
01073000	Oyster River Durham, NH	0.60 0.91 1.57	0.68 1.07 1.90	1.49 2.73 4.88	1.82 2.98 5.12	0.91 1.49 2.48	0.31 0.56 1.07	0.11 0.19 0.41	0.08 0.13 0.28	0.08 0.12 0.26	0.14 0.29 0.70	0.36 0.99 1.90	0.69 1.24 2.15
01174565	W Branch Swift R Shutesbury, MA	0.76 1.16 1.97	0.80 1.26 2.08	1.44 2.36 3.91	1.58 2.48 4.23	1.03 1.55 2.39	0.34 0.67 1.45	0.12 0.26 0.57	0.09 0.20 0.44	0.09 0.18 0.44	0.21 0.43 1.12	0.57 1.11 2.00	0.76 1.35 2.20
01097300	Nashoba Brook Acton, MA	0.65 1.10 2.12	0.86 1.49 2.35	1.65 2.75 4.29	1.68 2.75 4.39	0.94 1.49 2.35	0.39 0.64 1.25	0.12 0.26 0.52	0.06 0.16 0.36	0.06 0.15 0.32	0.14 0.35 0.79	0.45 0.94 1.80	0.71 1.21 2.35
01115187	Ponaganset R S Foster, RI	1.03 1.75 2.91	1.29 2.02 3.24	2.09 3.03 4.90	1.81 2.80 4.48	1.09 1.65 2.49	0.35 0.67 1.42	0.09 0.18 0.43	0.05 0.11 0.31	0.06 0.13 0.30	0.15 0.32 0.77	0.48 0.97 2.08	1.03 1.74 3.10
01111300	Nipmuc River Harrisville, RI	1.00 1.67 2.75	1.28 2.05 3.13	2.05 2.94 4.56	1.86 2.82 4.33	1.15 1.73 2.62	0.39 0.70 1.47	0.12 0.24 0.52	0.07 0.15 0.38	0.07 0.15 0.36	0.17 0.36 0.82	0.50 0.96 1.98	0.96 1.60 2.88
01126600	Blackwell Brook Brooklyn, CT	0.91 1.54 2.64	1.12 1.76 2.96	1.86 2.68 4.14	1.68 2.50 3.82	1.08 1.61 2.42	0.38 0.70 1.44	0.15 0.28 0.57	0.10 0.21 0.42	0.11 0.23 0.45	0.28 0.49 1.05	0.56 1.01 2.07	0.83 1.53 2.64

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:
75th percentile flow
50th percentile flow
25th percentile flow

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01161500	Tarbell Brook Winchendon, MA	0.70 1.03 1.70	0.74 1.08 1.73	1.07 1.95 3.79	2.11 3.40 5.56	1.03 1.57 2.49	0.37 0.70 1.51	0.21 0.35 0.65	0.15 0.25 0.53	0.12 0.24 0.49	0.22 0.42 1.03	0.48 1.07 1.78	0.76 1.30 2.16
01162500	Priest Brook Winchendon, MA	0.62 0.98 1.70	0.62 1.03 1.75	1.08 2.11 4.23	2.11 3.61 5.88	0.93 1.49 2.58	0.31 0.62 1.39	0.13 0.25 0.52	0.08 0.16 0.41	0.09 0.20 0.45	0.18 0.40 1.03	0.51 1.08 1.91	0.72 1.29 2.27
01187300	Hubbard River W Hartland, CT	0.80 1.11 2.01	0.75 1.21 2.06	1.36 2.51 4.52	1.76 3.07 5.73	0.90 1.51 2.76	0.29 0.55 1.41	0.12 0.24 0.50	0.08 0.16 0.41	0.10 0.19 0.49	0.24 0.50 1.31	0.75 1.31 2.56	0.90 1.51 2.61
01194500	E Br Eightmile R North Lyme, CT	1.14 1.83 3.07	1.34 2.10 3.45	2.10 2.94 4.55	1.87 2.73 4.33	1.25 1.92 2.94	0.42 0.80 1.61	0.17 0.29 0.66	0.11 0.22 0.49	0.12 0.25 0.49	0.33 0.54 1.03	0.71 1.16 2.27	1.06 1.92 3.24
01169900	South River Conway, MA	0.82 1.29 1.99	0.91 1.33 2.07	1.37 2.53 4.27	2.66 4.07 6.56	1.49 2.20 3.15	0.62 1.00 1.83	0.31 0.46 0.79	0.22 0.36 0.66	0.23 0.36 0.66	0.35 0.58 1.29	0.62 1.33 2.45	0.83 1.54 2.32
01121000	Mount Hope R Warrenville, CT	0.91 1.54 2.62	1.15 1.71 2.90	1.89 2.62 4.06	1.68 2.45 3.74	1.08 1.61 2.38	0.38 0.70 1.43	0.15 0.28 0.59	0.10 0.20 0.42	0.12 0.24 0.49	0.28 0.52 1.05	0.56 0.98 1.96	0.80 1.50 2.62
01199050	Salmon Creek, Lime Rock, CT	0.75 1.16 1.97	0.85 1.36 2.08	1.36 2.31 3.37	1.67 2.52 3.81	1.05 1.57 2.38	0.54 0.92 1.77	0.30 0.51 0.90	0.23 0.41 0.85	0.28 0.48 0.85	0.44 0.71 1.33	0.68 1.16 1.84	0.82 1.36 2.24
01123000	Little River Hanover, CT	0.97 1.63 2.67	1.17 1.83 2.83	1.80 2.53 3.73	1.77 2.47 3.47	1.23 1.73 2.47	0.57 0.90 1.57	0.33 0.47 0.73	0.26 0.37 0.60	0.24 0.33 0.53	0.33 0.53 0.93	0.60 1.07 1.87	0.90 1.60 2.67
01105730	Indian Head R Hanover, MA	1.25 1.95 3.14	1.48 2.24 3.60	2.05 3.14 4.72	1.72 2.57 4.13	1.12 1.61 2.38	0.50 0.86 1.52	0.22 0.38 0.73	0.19 0.33 0.73	0.19 0.33 0.69	0.36 0.63 1.29	0.83 1.35 2.57	1.16 1.85 3.20
01095220	Stillwater River Sterling, MA	0.73 1.11 1.95	0.80 1.28 2.13	1.45 2.42 4.21	1.56 2.49 4.33	1.00 1.52 2.38	0.31 0.64 1.32	0.09 0.22 0.47	0.06 0.17 0.38	0.06 0.14 0.31	0.16 0.35 0.94	0.50 1.04 1.90	0.73 1.31 2.20

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:
75th percentile flow
50th percentile flow
25th percentile flow

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01117800	Wood River Arcadia, RI	1.56 2.39 3.41	1.73 2.70 3.78	2.41 3.19 4.46	2.44 3.27 4.55	1.76 2.33 3.10	0.94 1.39 2.22	0.51 0.74 1.16	0.37 0.57 0.94	0.37 0.57 0.82	0.45 0.74 1.28	0.88 1.39 2.30	1.40 2.10 3.35
01332000	N Br Hoosic R N Adams, MA	0.80 1.19 2.02	0.81 1.22 2.17	1.48 2.63 4.45	2.48 3.82 5.98	1.34 2.14 3.31	0.66 1.05 1.81	0.34 0.55 0.90	0.24 0.39 0.78	0.21 0.39 0.84	0.34 0.70 1.54	0.80 1.51 2.45	1.09 1.70 2.78
01170100	Green River Colrain, MA	0.77 1.14 1.71	0.80 1.16 1.79	1.23 2.29 4.23	2.90 4.76 7.95	1.43 2.18 3.45	0.60 0.97 1.81	0.29 0.46 0.77	0.20 0.34 0.58	0.20 0.31 0.58	0.29 0.53 1.22	0.60 1.28 2.46	0.85 1.40 2.27
01333000	Green River Williamstown MA	0.75 1.13 1.88	0.77 1.17 2.02	1.38 2.46 4.11	2.32 3.54 5.59	1.27 2.00 3.08	0.63 1.01 1.69	0.33 0.52 0.85	0.23 0.38 0.75	0.21 0.38 0.80	0.33 0.70 1.46	0.75 1.38 2.25	1.03 1.62 2.61
01109000	Wading River Norton, MA	1.10 1.74 2.87	1.28 2.07 3.19	2.00 2.85 4.31	1.74 2.71 3.95	1.10 1.61 2.32	0.41 0.76 1.51	0.14 0.25 0.60	0.11 0.23 0.50	0.12 0.22 0.46	0.21 0.39 0.80	0.50 0.99 1.90	0.87 1.65 2.94
01198500	Blackberry River Canaan, CT	0.73 1.09 1.74	0.73 1.14 1.80	1.28 2.12 3.35	1.53 2.37 3.68	0.94 1.43 2.24	0.39 0.69 1.35	0.20 0.37 0.64	0.17 0.28 0.55	0.18 0.29 0.57	0.31 0.58 1.24	0.77 1.24 2.07	0.86 1.35 2.12
010965852	Beaver Brook N Pelham, NH	0.67 1.04 1.69	0.82 1.28 2.09	1.61 2.56 4.46	1.77 2.95 4.86	1.00 1.53 2.55	0.36 0.63 1.20	0.14 0.23 0.45	0.09 0.15 0.32	0.09 0.14 0.28	0.16 0.31 0.67	0.38 0.94 1.85	0.71 1.26 2.20
01198000	Green River Gr Barrington MA	0.69 1.03 1.79	0.77 1.17 1.83	1.24 2.23 4.14	1.91 2.97 5.10	1.17 1.71 2.61	0.41 0.70 1.39	0.19 0.31 0.58	0.13 0.25 0.53	0.13 0.24 0.46	0.23 0.43 1.04	0.49 1.13 2.03	0.80 1.33 2.18
01171500	Mill River Northampton MA	0.82 1.22 1.87	0.91 1.33 2.13	1.52 2.61 4.17	2.07 3.24 5.02	1.20 1.82 2.78	0.56 0.87 1.61	0.28 0.44 0.76	0.20 0.35 0.65	0.22 0.33 0.61	0.31 0.54 1.13	0.57 1.19 2.11	0.82 1.41 2.22
01084500	Beard Brook Hillsboro, NH	0.49 0.70 1.19	0.51 0.74 1.39	0.89 1.73 3.97	2.40 4.08 7.66	1.06 1.89 3.18	0.26 0.54 1.18	0.09 0.18 0.38	0.06 0.12 0.27	0.06 0.11 0.28	0.16 0.38 1.01	0.48 1.19 2.23	0.73 1.10 1.89
01096000	Squannacook R W Groton, MA	0.82 1.29 2.01	0.93 1.41 2.21	1.57 2.59 4.41	2.06 3.27 5.05	1.21 1.81 2.75	0.52 0.86 1.52	0.27 0.41 0.66	0.20 0.31 0.49	0.19 0.27 0.44	0.27 0.42 0.75	0.50 1.02 1.87	0.80 1.38 2.29

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:
75th percentile flow
50th percentile flow
25th percentile flow

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01082000	Contoocook R Peterborough NH	0.75 1.16 1.90	0.81 1.31 2.16	1.49 2.73 4.88	1.82 2.98 5.12	0.91 1.49 2.48	0.31 0.56 1.07	0.11 0.19 0.41	0.08 0.13 0.28	0.08 0.12 0.26	0.14 0.29 0.70	0.36 0.99 1.90	0.69 1.24 2.15
01154000	Saxtons River Saxtons, VT	0.60 0.84 1.32	0.58 0.86 1.44	1.03 1.91 3.60	2.43 4.06 6.76	1.07 1.75 2.81	0.41 0.69 1.28	0.19 0.31 0.54	0.14 0.23 0.43	0.14 0.23 0.45	0.24 0.48 1.03	0.46 1.12 2.08	0.71 1.11 1.81
01118000	Wood River Hope Valley, RI	1.52 2.27 3.30	1.70 2.59 3.64	2.35 3.11 4.38	2.33 3.11 4.40	1.74 2.28 3.05	0.93 1.33 2.12	0.51 0.73 1.13	0.40 0.57 0.90	0.39 0.59 0.86	0.46 0.70 1.20	0.82 1.27 2.14	1.32 2.04 3.20
01120000	Hop Brook Columbia, CT	0.94 1.50 2.49	1.11 1.69 2.73	1.78 2.46 3.81	1.58 2.28 3.43	1.05 1.53 2.25	0.38 0.70 1.40	0.17 0.30 0.58	0.12 0.23 0.45	0.15 0.27 0.55	0.35 0.58 1.05	0.62 1.10 2.01	0.85 1.50 2.49
01089000	Soucook River Concord, NH	0.58 0.82 1.26	0.58 0.91 1.52	1.05 1.97 3.73	1.91 3.19 5.10	1.01 1.52 2.33	0.36 0.64 1.08	0.15 0.27 0.51	0.12 0.19 0.35	0.10 0.15 0.30	0.18 0.36 0.77	0.42 0.95 1.68	0.64 1.03 1.86
01155000	Cold River Drewsville, NH	0.48 0.69 1.09	0.50 0.72 1.18	0.80 1.57 3.10	1.99 3.38 5.74	0.92 1.51 2.40	0.35 0.61 1.16	0.17 0.26 0.44	0.11 0.18 0.34	0.11 0.19 0.35	0.19 0.35 0.79	0.37 0.89 1.75	0.58 0.89 1.50
01169000	North River Shattuckville, MA	0.79 1.12 1.75	0.81 1.18 1.80	1.28 2.31 4.20	2.80 4.66 7.70	1.35 2.07 3.31	0.56 0.92 1.79	0.29 0.45 0.76	0.20 0.34 0.58	0.20 0.31 0.62	0.31 0.57 1.25	0.63 1.32 2.43	0.84 1.45 2.29
01111500	Branch River Forestdale, RI	1.14 1.84 2.85	1.43 2.07 3.13	2.03 2.85 4.32	1.77 2.65 4.21	1.27 1.75 2.53	0.57 0.90 1.58	0.31 0.45 0.70	0.24 0.37 0.61	0.26 0.38 0.70	0.48 0.81 1.25	0.81 1.27 2.12	1.07 1.75 3.07
01181000	W Br Westfield R Huntington, MA	0.79 1.15 1.85	0.85 1.26 1.94	1.36 2.38 4.40	2.24 3.66 6.28	1.24 1.89 3.05	0.46 0.78 1.57	0.21 0.35 0.66	0.15 0.28 0.57	0.15 0.27 0.53	0.27 0.51 1.27	0.64 1.29 2.28	0.89 1.47 2.41
01117500	Pawcatuck River Wood R Jct, RI	1.52 2.12 3.09	1.72 2.52 3.45	2.33 3.06 4.13	2.25 3.11 4.35	1.81 2.29 3.06	1.11 1.50 2.16	0.62 0.85 1.25	0.48 0.68 1.05	0.46 0.61 0.92	0.49 0.69 1.03	0.73 1.09 1.78	1.21 1.79 2.58
01091000	S Br Piscataquog Goffstown, NH	0.69 1.07 1.76	0.76 1.26 2.04	1.31 2.38 4.35	1.95 3.38 5.72	1.04 1.62 2.63	0.39 0.69 1.30	0.16 0.27 0.51	0.12 0.19 0.34	0.10 0.17 0.31	0.18 0.31 0.62	0.38 0.96 1.76	0.73 1.21 2.19

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:
75th percentile flow
50th percentile flow
25th percentile flow

Table 2.2 Summary of Quartile Flows for Index Gages, 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01193500	Salmon River E Hampton CT	1.00 1.60 2.83	1.20 1.83 3.03	1.90 2.65 4.10	1.77 2.60 3.84	1.23 1.76 2.68	0.46 0.83 1.58	0.20 0.35 0.70	0.15 0.27 0.54	0.14 0.27 0.56	0.29 0.52 0.95	0.65 1.08 1.98	0.92 1.61 2.83
01176000	Quaboag River W Brimfield, MA	0.93 1.50 2.40	1.00 1.53 2.57	1.76 2.69 4.13	2.19 3.20 4.70	1.28 1.87 2.66	0.53 0.87 1.55	0.29 0.48 0.75	0.23 0.40 0.67	0.19 0.30 0.57	0.35 0.57 1.13	0.63 1.12 2.00	0.81 1.55 2.53
01200000	Ten Mile River CT	0.80 1.20 1.99	0.89 1.35 2.25	1.62 2.43 3.72	1.58 2.39 3.55	1.02 1.50 2.30	0.48 0.78 1.52	0.23 0.40 0.75	0.17 0.30 0.67	0.15 0.27 0.51	0.21 0.39 0.96	0.40 0.86 1.71	0.69 1.35 2.25
01108000	Taunton River Bridgewater, MA	1.25 2.04 3.16	1.54 2.45 3.67	2.23 3.16 4.51	1.89 2.92 4.41	1.30 1.87 2.68	0.59 0.95 1.70	0.31 0.46 0.80	0.25 0.38 0.68	0.24 0.37 0.64	0.31 0.47 0.95	0.59 1.04 1.99	1.04 1.64 2.90
01118500	Pawtucket River Westerly, RI	1.48 2.18 3.21	1.69 2.49 3.54	2.27 3.01 4.22	2.18 3.02 4.32	1.66 2.13 2.95	0.93 1.35 2.08	0.52 0.72 1.08	0.41 0.58 0.91	0.36 0.55 0.79	0.42 0.63 1.00	0.72 1.08 1.93	1.21 1.84 2.84

Note: All values are flows in cfs per square mile of drainage area, or cfsm. Values are shown as:

75th percentile flow
50th percentile flow
25th percentile flow

Table 2.3 Summary of Median of Mean Monthly Flows for Index Gages (ABF approach) 1960 to 2004 Data

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01174900	Cadwell Creek Belchertown, MA	2.20	1.81	3.98	4.19	2.40	1.07	0.51	0.40	0.29	0.70	1.71	2.02
01174000	Hop Brook New Salem, MA	1.82	1.56	3.69	4.59	2.29	1.13	0.43	0.27	0.20	0.45	1.38	1.75
01093800	Stony Brook Trib Temple, NH	1.44	1.45	3.61	5.33	2.53	1.02	0.36	0.23	0.37	0.59	1.98	1.56
01118300	Pendleton Hill Bk Clarks Falls, CT	2.75	3.15	3.79	3.64	2.36	1.10	0.50	0.31	0.35	0.67	1.55	2.33
01105600	Old Swamp River Weymouth, MA	2.42	2.68	3.28	2.87	1.65	0.82	0.39	0.47	0.50	0.72	1.65	1.99
01115098	Peeptoad Brook Westerly, RI	2.55	3.11	3.92	3.93	1.99	0.93	0.24	0.25	0.31	0.38	1.41	2.27
01100700	E Meadow River Haverhill, MA	1.94	2.25	4.97	5.68	2.75	1.10	0.45	0.33	0.30	0.52	1.45	1.88
01171800	Bassett Brook Northampton MA	1.35	1.48	2.92	3.43	1.76	0.93	0.47	0.43	0.40	0.58	1.33	1.45
01195100	Indian River Clinton, CT	2.08	2.36	2.91	2.87	1.77	0.85	0.28	0.22	0.22	0.48	1.20	1.84
01085800	W Br Warner R Bradford, NH	1.10	1.09	2.99	6.10	2.59	0.91	0.33	0.24	0.26	0.53	2.07	1.43
01187400	Valley Brook W Hartland, CT	1.60	1.53	3.76	3.85	2.26	1.01	0.37	0.35	0.29	0.71	1.86	2.15
01331400	Dry Brook Adams, MA	1.52	1.40	3.98	5.75	2.37	0.99	0.43	0.29	0.39	0.86	1.80	1.79
01106000	Adamsville Brook Adamsville, RI	2.33	3.00	3.60	3.30	1.99	0.99	0.30	0.24	0.25	0.45	1.38	2.20
01115630	Nooseneck River Nooseneck, RI	2.81	3.25	3.87	3.87	2.56	1.59	0.81	0.64	0.61	0.83	1.84	2.40
01175670	Sevenmile River Spencer, MA	1.71	1.86	3.27	3.73	1.97	0.84	0.48	0.29	0.22	0.43	1.04	1.65
01117468	Beaver River, Usquepaug, RI	2.85	3.05	3.71	4.16	2.80	1.66	0.87	0.75	0.66	0.75	1.57	2.34
01184100	Stony Brook W Suffield, CT	1.74	1.69	3.45	3.60	2.03	0.79	0.32	0.30	0.23	0.65	1.62	1.73

Note: Values are the median of all monthly means from 1960 to 2004.
Note: All values are flows in cfs per square mile of drainage area, or cfsm.

Table 2.3 Summary of Median of Mean Monthly Flows for Index Gages (ABF approach) 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01165500	Moss Brook Wendell, MA	1.40	1.34	2.81	4.03	1.99	0.96	0.43	0.28	0.34	0.53	1.19	1.51
01073000	Oyster River, Durham, NH	1.27	1.50	3.51	3.71	1.80	0.84	0.23	0.20	0.18	0.47	1.21	1.41
01174565	W Branch Swift R Shutesbury, MA	1.80	1.44	3.30	3.41	1.95	0.89	0.42	0.37	0.25	0.59	1.43	1.65
01097300	Nashoba Brook Acton, MA	1.49	1.65	3.32	3.54	1.72	0.86	0.34	0.25	0.21	0.46	1.21	1.35
01115187	Ponaganset R S Foster, RI	2.24	2.39	3.84	3.54	1.85	0.80	0.23	0.15	0.21	0.55	1.24	2.15
01111300	Nipmuc River Harrisville, RI	2.41	2.37	3.67	3.50	2.28	0.89	0.33	0.22	0.29	0.62	1.27	1.85
01126600	Blackwell Brook Brooklyn, CT	2.25	2.44	3.38	3.04	2.04	0.85	0.43	0.31	0.33	0.69	1.39	1.77
01161500	Tarbell Brook Winchendon, MA	1.18	1.18	2.57	4.44	1.96	0.92	0.51	0.30	0.30	0.47	1.21	1.52
01162500	Priest Brook Winchendon, MA	1.30	1.20	3.13	4.66	1.95	0.90	0.43	0.24	0.30	0.50	1.32	1.64
01187300	Hubbard River, W Hartland, CT	1.73	1.69	3.86	3.98	2.29	0.84	0.35	0.33	0.31	0.71	1.88	2.17
01194500	E Br Eightmile R N Lyme, CT	2.56	2.79	3.79	3.44	2.28	0.86	0.42	0.31	0.43	0.77	1.40	2.10
01169900	South River, Conway, MA	1.52	1.54	3.37	5.37	2.70	1.11	0.52	0.43	0.50	0.75	1.67	1.83
01121000	Mount Hope River Warrenville, CT	2.24	2.32	3.35	3.00	2.15	0.77	0.43	0.32	0.34	0.69	1.39	1.65
01199050	Salmon Creek Lime Rock, CT	1.65	1.51	2.71	3.03	1.96	1.11	0.67	0.48	0.60	0.77	1.37	1.59
01123000	Little River Hanover, CT	2.30	2.15	3.18	3.05	1.96	1.04	0.58	0.45	0.44	0.67	1.29	1.86
01105730	Indian Head River Hanover, MA	2.43	2.80	3.48	3.15	1.79	1.00	0.41	0.42	0.50	0.79	1.74	2.06

Note: Values are the median of all monthly means from 1960 to 2004.
Note: All values are flows in cfs per square mile of drainage area, or cfsm.

Table 2.3 Summary of Median of Mean Monthly Flows for Index Gages (ABF approach) 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01095220	Stillwater River Sterling, MA	1.85	1.54	3.73	3.83	1.88	0.83	0.43	0.34	0.21	0.44	1.40	1.74
01117800	Wood River Arcadia RI	2.77	2.80	3.50	3.70	2.45	1.46	0.81	0.61	0.62	0.80	1.66	2.24
01332000	N Br Hoosic River N Adams, MA	1.71	1.58	3.61	4.80	2.51	1.18	0.64	0.47	0.52	0.79	1.80	1.93
01170100	Green River Colrain, MA	1.22	1.40	3.02	6.24	2.70	1.14	0.59	0.42	0.42	0.76	1.67	1.63
01333000	Green River Williamstown, MA	1.61	1.53	3.34	4.33	2.23	1.14	0.62	0.44	0.50	0.76	1.74	1.81
01109000	Wading River Norton, MA	2.10	2.45	3.05	3.12	1.70	0.89	0.29	0.33	0.38	0.43	1.18	1.89
01198500	Blackberry River Canaan, CT	1.46	1.42	2.66	2.79	1.80	0.98	0.49	0.44	0.38	0.75	1.47	1.70
010965852	Beaver Brook Pelham NH	1.37	1.61	3.35	3.64	1.94	0.93	0.28	0.23	0.21	0.41	1.11	1.40
01198000	Green River Gr Barrington MA	1.41	1.43	3.35	3.93	1.98	0.90	0.42	0.35	0.30	0.54	1.46	1.59
01171500	Mill River Northampton MA	1.60	1.76	3.54	4.23	2.10	1.14	0.55	0.49	0.46	0.70	1.57	1.75
01084500	Beard Brook Hillsboro, NH	1.06	1.06	3.07	6.05	2.50	0.80	0.34	0.21	0.19	0.45	1.92	1.31
01096000	Squannacook R W Groton, MA	1.45	1.71	3.41	4.12	2.20	0.98	0.44	0.38	0.35	0.50	1.16	1.57
01082000	Contoocook R Peterborough NH	1.50	1.56	3.29	4.43	2.34	1.10	0.52	0.42	0.40	0.52	1.23	1.54
01154000	Saxtons River Saxtons, VT	1.08	1.07	2.69	5.51	2.24	0.91	0.41	0.30	0.37	0.66	1.47	1.27
01118000	Wood River Hope Valley, RI	2.54	2.77	3.36	3.62	2.42	1.48	0.79	0.59	0.62	0.78	1.52	2.25
01120000	Hop Brook Columbia, CT	2.07	2.24	3.09	2.78	1.91	0.77	0.44	0.37	0.37	0.72	1.38	1.64

Note: Values are the median of all monthly means from 1960 to 2004.
Note: All values are flows in cfs per square mile of drainage area, or cfsm.

Table 2.3 Summary of Median of Mean Monthly Flows for Index Gages (ABF approach) 1960 to 2004 Data (continued)

USGS Gage #	Gage Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01089000	Soucook River Concord, NH	1.03	1.09	2.66	4.13	1.79	0.86	0.33	0.22	0.19	0.44	1.07	1.14
01155000	Cold River Drewsville, NH	0.82	0.87	2.25	4.44	1.89	0.76	0.34	0.23	0.28	0.52	1.22	1.07
01169000	North River Shattuckville, MA	1.35	1.49	3.30	6.18	2.63	1.25	0.60	0.43	0.51	0.81	1.79	1.75
01111500	Branch River Forestdale, RI	2.30	2.42	3.38	3.43	2.02	0.93	0.50	0.43	0.54	0.83	1.30	2.02
01181000	W Br Westfield R Huntington, MA	1.48	1.53	3.58	4.66	2.64	1.02	0.48	0.42	0.34	0.61	1.66	1.83
011175000	Pawcatuck River Wood R Jct, RI	2.41	2.74	3.08	3.41	2.43	1.52	0.91	0.81	0.69	0.72	1.13	1.87
01193500	Salmon River E Hampton, CT	2.28	2.38	3.30	3.17	2.23	0.89	0.46	0.35	0.37	0.66	1.48	1.85
01091000	S Br Piscataquog Goffstown, NH	1.31	1.44	3.45	4.35	2.17	0.81	0.32	0.26	0.23	0.36	1.13	1.33
01176000	Quaboag River W Brimfield, MA	1.83	1.80	2.97	3.90	2.05	0.87	0.55	0.45	0.35	0.64	1.17	1.59
01200000	Ten Mile River CT	1.41	1.70	3.05	2.61	1.70	0.95	0.53	0.41	0.31	0.37	1.04	1.59
01108000	Taunton River Bridgewater, MA	2.50	2.70	3.52	3.52	1.88	1.01	0.46	0.45	0.41	0.49	1.34	1.95
01118500	Pawtucket River Westerly, RI	2.59	2.66	3.14	3.48	2.24	1.37	0.79	0.67	0.61	0.69	1.22	2.14

Note: Values are the median of all monthly means from 1960 to 2004.
Note: All values are flows in cfs per square mile of drainage area, or cfsm

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Appendix A

Summary of Streamflow Requirements and Streamflow Characteristics at Index Stations in Southern New England (after Armstrong, 2004)

Summary of Streamflow Requirements and Streamflow Characteristics at Index Stations in Southern New England (after Armstrong, 2004)

Method	Discharge per unit Drainage basin area (cfsm)	Annual Flow Duration (percent exceedance)
High-Flow Group		
RVA 75th percentile (highest percentile, Jul-Sep)	1.3	54
Tennant 40-percent mean annual flow	0.83	69
R2Cross 3-of-3 criteria	0.73	76
Tennant 30-percent mean annual flow	0.62	77
ABF median of August Mean	0.57	78
Canadian Atlantic Provinces 25-percent mean annual flow	0.52	82
R2Cross 2-of-3 criteria	0.49	87
RVA 25th percentile (lowest percentile, Jul-Sep)	0.37	89
Wetted Perimeter	0.33	94
Tennant 10-percent mean annual flow	0.21	97
Low-Flow Group		
RVA 75th percentile (highest percentile, Jul-Sep)	0.84	59
R2Cross 3-of-3 criteria	0.84	60
Tennant 40-percent mean annual flow	0.77	61
Tennant 30-percent mean annual flow	0.58	69
Canadian Atlantic Provinces 25-percent mean annual flow	0.48	73
ABF median of August Mean	0.45	75
Wetted Perimeter	0.39	79
R2Cross 2-of-3 criteria	0.35	81
RVA 25th percentile (lowest percentile, Jul-Sep)	0.21	89
Tennant 10-percent mean annual flow	0.19	91

Appendix B: Target Hydrographs for Index Gages

Appendix C: IHA Statistics for Index Gages

Appendix D. Massachusetts Gage Characteristics

Appendix E: Annual Target Hydrograph Analysis